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Towards the development of legislative framework for solar neighborhoods

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The growing implementation of sustainable urban infrastructure, utilizing solar energy for heat and power generation, daylighting, and thermal comfort, has intensified the focus on sustainability standards and guidelines. Nevertheless, a noticeable deficiency persists in regulations that specifically address solar energy access and protection, posing a barrier to the diffusion of solar-centric neighborhoods. This paper examines the traditional urban regulatory frameworks and the state of solar energy regulations and practices within five countries (i.e., Canada, Italy, Norway, Sweden, and Switzerland). The aim of the study is to (i) identify gaps in existing regulations, standards, and codes, (ii) highlight the need for future regulations to protect solar access and rights, and (iii) support the deployment of solar technologies on a large scale. The results underline that climate-related regulations often fall short of specificity tailored to regional and local climates, relying on generalized climate considerations. Solar energy legislation is generally scarce and lacks comprehensive planning. Finally, despite various financial incentives for the installation of active solar strategies, their impact remains limited, impeding the wide spread of solar technology as a primary source of energy production in urban environment.

KEYWORDS

solar neighborhoods, regulations and policies, high-performance codes, solar access, planning framework

1 Introduction

Globally, neighborhoods are adopting more sustainable practices to tackle environmental challenges like climate change and pollution, aiming for resilience and livability (Krangsås et al., 2021). Driven by challenges such as climate change, resource depletion, pollution, and the goal of fostering livable and resilient communities, local

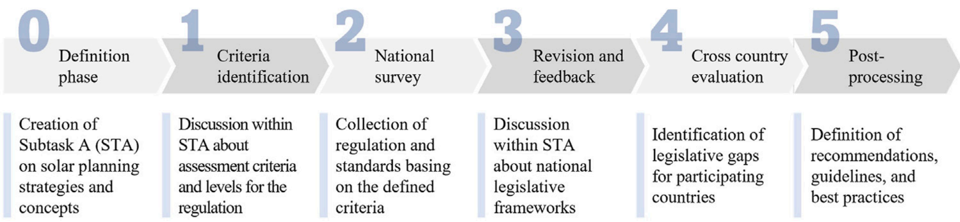

FIGURE 1
Workflow followed in this study.

governments are updating zoning and land use regulations to promote mixed-use and transit-oriented development, along with higher-density housing (Cheshmehzangi and Butters, 2016; Mathur and Gatdula, 2023). Cities are implementing policies to encourage walkable, mixed-use neighborhoods, reducing car dependency and promoting sustainable transportation, with street networks, sidewalks, and cycling lanes as key sustainable features (Mosaberpanah and Khales, 2013; Gupta et al., 2019). Moreover, building codes and green building standards are being updated to mandate energy-efficient practices, including efficient appliances, improved insulation, renewable energy installations, and sustainable materials.

Worldwide examples demonstrate methods for incorporating sustainability into neighborhood design. The city of Edmonton (Canada) emphasizes physical, economic, and social dimensions as key elements in new neighborhood development (City of Edmonton, 2013). Europe has ambitious plans for sustainable neighborhood development and regeneration, exemplified by the "Positive Energy Districts and Neighborhoods for Sustainable Urban Development" program, aiming for 100 Positive Energy Neighborhoods across 20 EU states by 2025 (SET-Plan Working Group, 2018). Similarly, 20 Swedish cities aim for climate neutrality by 2030, focusing on sustainable neighborhood strategies and research funding.

A similar attention towards the integration of sustainable practices in the design of neighborhoods is also visible in the current research trends. For instance (Luederitz et al., 2013), presented an approach in designing sustainable neighborhoods that include various stakeholders. Asarpota and Nadin (2020) identified several urban components for the energy transition in modern neighborhoods including transport and accessibility, urban form and energy infrastructure. Hachem-Vermette (2022), Singh et al. (2023) presented the role of solar energy in the design of sustainable high - performance neighborhoods implementing various strategies such as rooftop and facade photovoltaic (PV) panels, solar thermal (ST) collectors, and thermal storage.

The emphasis on renewable energy and energy efficiency in construction has prompted the creation of various standards and guidelines, such as the Leadership in Energy and Environmental Design (LEED) rating system, to encourage sustainable energy use, incorporating criteria like compact development and smart location (Chicago Metropolitan Agency for Planning, 2008). Consequently, numerous countries have established building codes mandating that new constructions and renovations adhere to precise energy efficiency specifications. The EU's Energy Performance of Buildings Directive (EPBD, 2010) (European Union, 2010) mandates energy efficiency standards, certifications, nearly zero-energy buildings, and smart readiness indicators, complemented by government incentives for renewable installations in residential areas (Abdmouleh et al., 2015). However, integration into a cohesive regulatory framework remains challenging.

A unified system that merges individual sustainability and energy efficiency standards is necessary. Some nations, like Switzerland, are advancing towards a holistic model, particularly in building and neighborhood development, through self-consumer communities facilitated by federal subsidies covering up to 30% of investments and legislation supporting solar energy sharing via microgrids.

Despite this growing attention to sustainable development and practices, standards or regulations that focus on solar accessibility and preservation, and the implementation of solar technology are still scarce to non-existent. Formolli et al. (2021) identified weaknesses in Scandinavian solar energy legislations, challenging municipalities in promoting solar technology adoption and consequently hindering solar neighborhood development. Furthermore, the lack of such regulations can hinder the development of solar neighborhoods. Solar neighborhoods prioritize optimal solar utilization in an urban, suburban, or rural setting and have several features such as passive strategies (i.e., equatorial windows, solar chimneys, skylights, etc.), and active solar strategies (i.e., PV installations on rooftops, façades, and parking lots) intending to maximize useful solar gain in buildings and outdoor neighborhood surfaces (Hachem-Vermette, 2020; Manni et al., 2023). These design features can result in many benefits such as enhance passive heating/cooling in buildings, reduce overall energy consumption, and enable adequate thermal and visual comfort indoors and outdoors.

The development of solar neighborhoods faces challenges stemming from climatic conditions, sunlight availability, community size and density, land use, and socio-economic factors. Given the uniqueness of each neighborhood in terms of location, land use, climate, and regulations, implementing solar strategies requires critical evaluation of site-specific parameters (Armstrong et al., 2021) These parameters along with occupant energy use behavior and energy systems further govern the energy demand profiles that influence the adoption of solar strategies. Further, continuous technological advancements and innovation in solar technologies can introduce several challenges in developing general strategies ensuring compatibility and scalability (Thakur et al., 2022).

Regulatory and policy frameworks are increasingly needed for safeguarding solar access, establishing solar rights for passive and active use, and to facilitate the planning and management of renewable energy

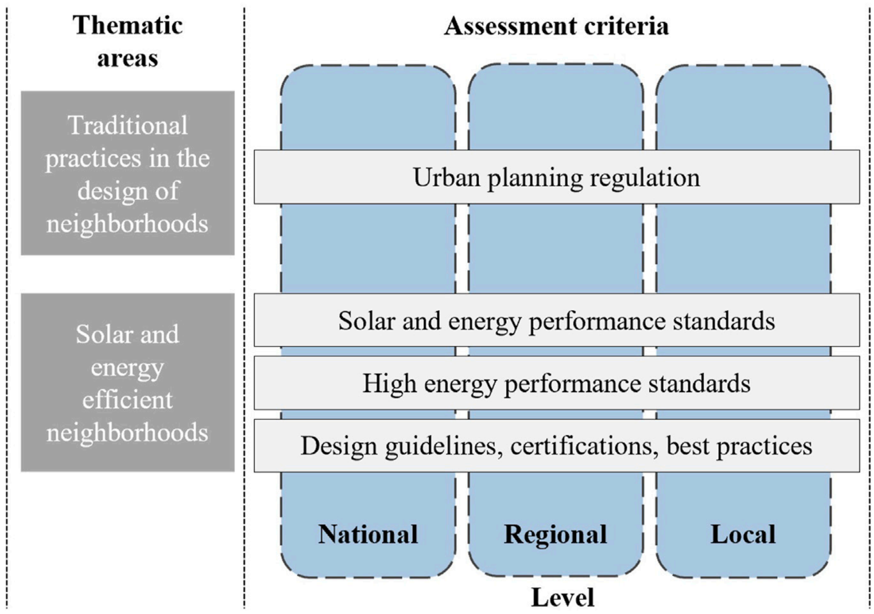

FIGURE 2
Overview of the thematic areas, assessment criteria, and levels of standards considered when evaluating the legislative framework of the participating countries.

generation with respect to existing infrastructure. For instance, utility infrastructure in neighborhoods might require updating to allow grid connectivity of PV electricity generation (Denholm and Margolis, 2007). In addition, financial barriers associated with significant upfront cost of solar installations, retrofits, energy storage systems, and grid connectivity (e.g., microgrid infrastructure) can also affect the financial viability of solar neighborhoods (Rai et al., 2016). Integrating financial incentives for solar technologies into regulatory frameworks, through mechanisms like tax credits, rebates, feed-in tariffs, and net metering, enhances solar adoption by improving financial viability.

This paper was developed within the framework of the International Energy Agency (IEA) Solar Heating & Cooling (SHC) Task 63 "Solar Neighborhood Planning" (2019–2024) (IEA SHC Task 63). The study aims at reviewing existing practices in the design of traditional neighborhoods and more advanced solar and energy-oriented neighborhoods in five different countries (i.e., Canada, Italy, Norway, Sweden, Switzerland). The aim of this review is to shed light on the general urban regulations and the current state of solar energy regulations and practices within the presented countries, helping to identify areas where improvements are needed.

2 Methodology

This section outlines the methodology employed to identify legislative gaps and the analysis criteria. A five-step workflow (Figure 1) is developed based on continuous dialogue between IEA SHC Task 63 international experts and national platforms.

Step 0: involved preliminary activities during which, objectives of the IEA SHC Task 63 were established, including reviewing regulations, standards, and practices across various administrative levels (e.g., national, regional, local).

Step 1: identifies thematic areas, such as i) traditional practices in neighborhood design and ii) solar and energy efficient neighborhoods); the assessment criteria, including i) urban planning regulation, ii) solar and energy performance standards, iii) high energy performance standards, iv) design guidelines, certification, and best practices; and finally the levels of the standard, ranging from national to regional and local. These levels categorize regulations and standards across participating countries, focusing on urban planning and energy performance criteria (Figure 2).

Step 2: involves gathering data on the legislative frameworks of participating countries based on Step 1 criteria, setting the groundwork for reviewing and discussing legislative advancements in Step 3. Step 4 includes the activities related to cross country evaluation and gap analysis, which resulted in reports, interviews, and meetings with the Task 63 experts.

In Step 5, information from previous stages is synthesized into recommendations, guidelines, and best practices to guide future legislative directions for new and existing solar neighborhoods.

3 Traditional practices in the design of neighborhoods

This section outlines traditional neighborhood planning approaches, characterized by conventional design processes with limited emphasis on energy and resource efficiency.

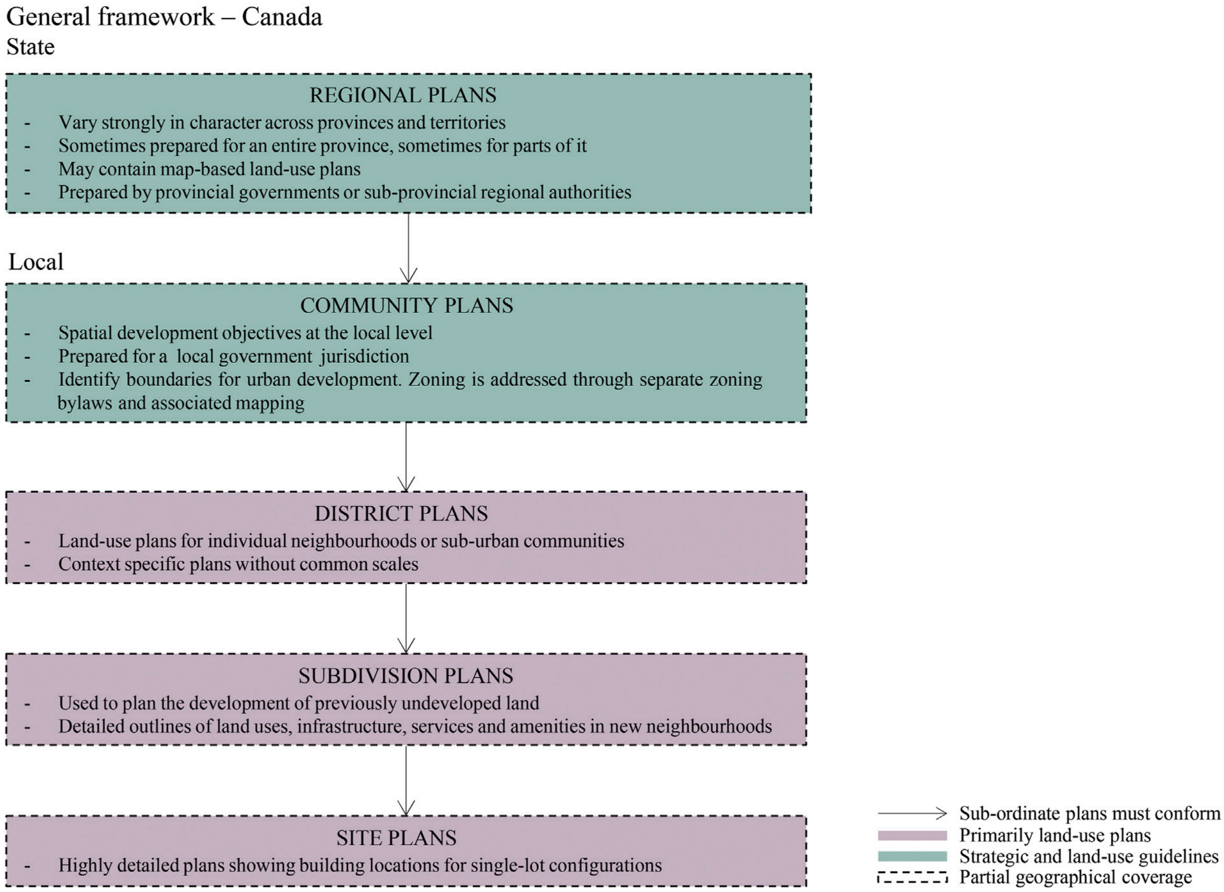

FIGURE 3
General framework, Canada. Adapted from (OECD, 2017).

3.1 Urban regulations and common practices

This paper examines urban design regulations as administrative tools for shaping public spaces and the built environment, focusing on building placement, street relations, and surrounding area (Kumar, 2002). It explores the intersection of land use and urban design regulations, highlighting their impact on building types, neighborhood energy intensity, and overall urban fabric, including green spaces and other elements. The analysis covers regulatory practices across various countries, emphasizing general rules, climate considerations in traditional regulations, and regulated aspects.

3.2 General regulations

General regulations governing urban planning are presented below, for each of the considered countries capturing a spectrum of legislative frameworks.

3.2.1 Canada

Three levels of governmental systems are in place in Canada: federal, provincial and municipal (Figure 3). Urban design regulations are better addressed at municipality level. Although provincial planning legislation does exist, there is no direct reference to the expression “Urban Planning”. As such, municipalities derive various regulations pertaining to urban planning by referring to different sections related to land use, site plan and others.

Surveys reveal that major Canadian municipalities implement urban design regulations, including zoning by-laws, policy statements, and heritage preservation policies (Kumar, 2002). Comprehensive urban design standards often remain undeveloped, despite the existence of detailed plans and guidelines. The following outlines prevalent regulations and practices in Canada.

Municipal zoning bylaws: municipalities are the main regulating party to control land use and development within their jurisdiction. These rules and regulations are documented and governed by bylaws. Primarily, these bylaws govern the type of building land use and density of buildings within a specific neighborhood. For instance, a zoning bylaw mentions if a particular area is only being used for single-family housing, whereas a different area may be zoned for mixed used developments.

Official community plans (OCPs): Canadian municipalities OCPs to direct long-term community development, encompassing land use, transportation, housing, utilities, and

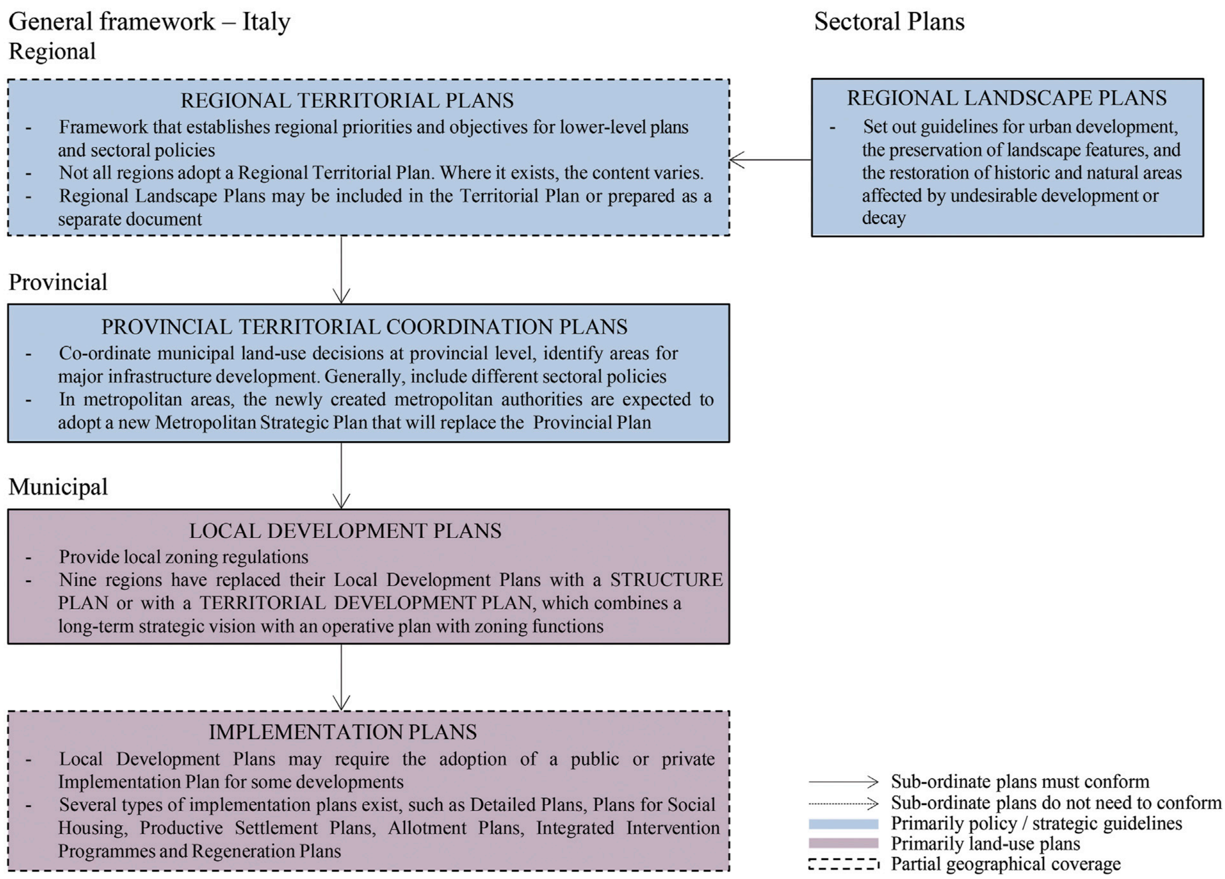

FIGURE 4
General framework, Italy. Adapted from (OECD, 2017).

sustainability. These OCPs, mandatorily integrated into neighborhood planning, are periodically revised. For instance, Vancouver's OCP, established in 1980 and renewed in 2022, guides urban planning towards a livable, affordable, and sustainable city framework (City of Vancouver, 2022).

Other regulations and practices include public consultations, heritage preservation, environmental regulations, and transportation and infrastructure planning.

3.2.2 Italy

The Italian legal framework on urban and energy planning is characterized by a hierarchical approach stretching from the national level down to the regional, provincial, and municipal levels (Figure 4). According to the Constitution, urban planning and energy-related topics are a shared responsibility between the State, the Regions, and the Autonomous Provinces. Consequently, the regional authorities can implement autonomous legislation, as long as it does not contradict the general principles and requirements set by national and EU regulations. In particular, the regional, provincial and municipal urban planning instruments define strategies and operational objectives (Land-use Planning Systems in the OECD, 2017). The main types of plans are:

Territorial Coordination Plans (PTC) can be adopted at both regional and provincial level to coordinate the programming and urban planning activities of the local authorities. The content of PTCs focuses on the following areas: individuation of work and production areas, urban and rural settlements, landscape areas, social services and facilities, and communication and transport networks.

General Regulatory Plans (PRG) are local development frameworks ranging from scales of 1:5,000 to 1:2,000, applicable municipally or inter-municipally, refining the directives of Territorial Coordination Plans and national legislation. They encompass the entire municipal territory, detailing (i) transportation networks, (ii) zoning, (iii) public spaces and buildings, (iv) conservation areas, and (v) implementation rules. Regulations, including building density, spacing, and parking provisions. PRGs also mandate specific construction standards to safeguard environmental and historical sites, with implementation plans at 1:2,000 to 1:1,000 scales for executing public and private projects, ensuring detailed adherence to PRG guidelines for urban development. The PRG mandates building density, height, and spacing limits, requires minimum parking space allocation in new constructions, and enforces setback distances to safeguard the road network outside built-up areas. At scales from 1:2,000 to 1:1,000, the PRG is executed through implementation plans of public and private initiatives, serving as executive technical instruments to detail PRG provisions and facilitate comprehensive urban intervention.

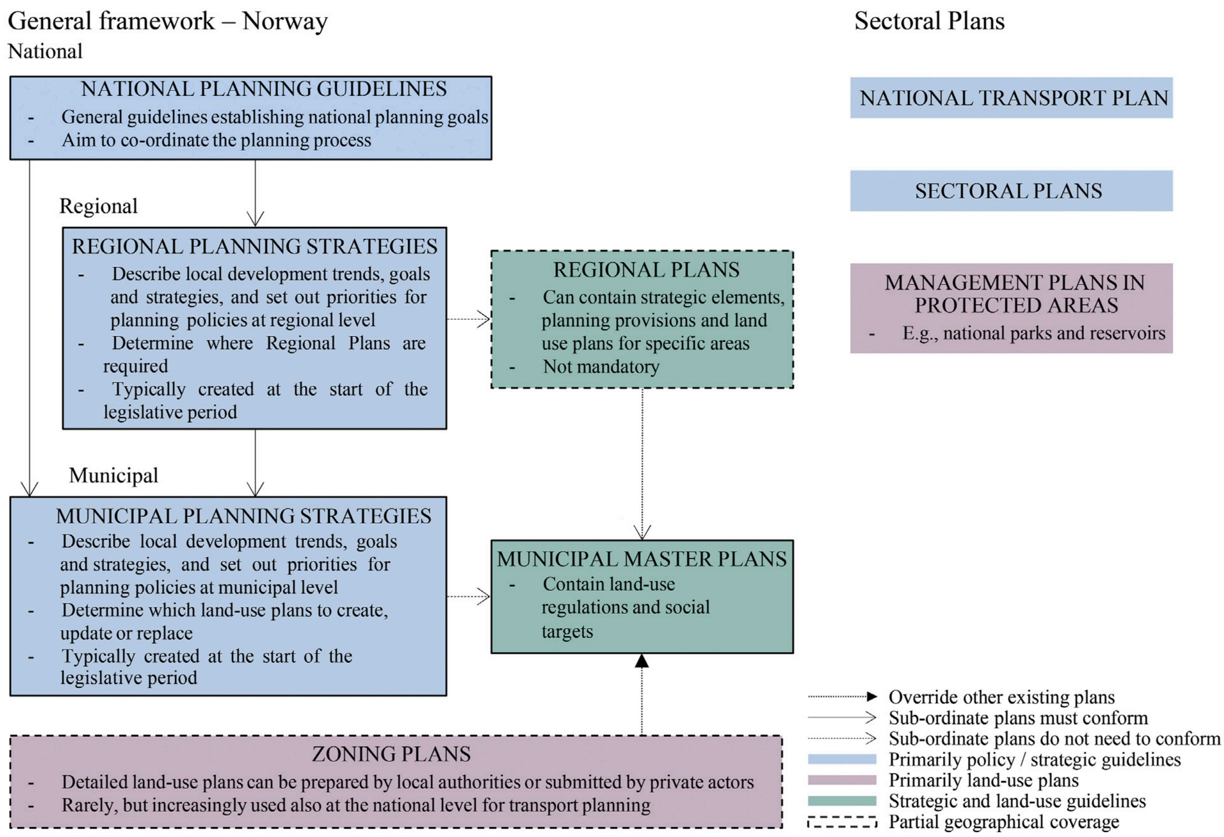

FIGURE 5
General framework, Norway. Adapted from (OECD, 2017).

3.2.3 Norway

In Norway, the main legislative frameworks (Figure 5) to address planning, building permits, and land use are summarized in the Planning and Building Act (Plan-og bygningsloven, 2008). Three levels of government—national, regional, and municipal—have distinct responsibilities. *The national government* sets overarching policies for counties and municipalities. It has minimal direct land-use planning involvement, except for major transportation projects. Regional governments oversee local authority plans and adopt plans focusing on regional priorities such as land use, transport, and environmental conservation, with urban areas emphasizing inter-municipal coordination despite limited influence. The greater responsibilities regarding planning are granted to *municipal governments*. They control the development at a local scale using *Municipal Master Plans* and *Zoning Plans*. The first ones cover all the areas of a municipality and represent their main spatial planning tools. In them it is possible to find general guidelines, strategic plans, and land-use plans with a scale spanning from 1:20,000 for small municipalities to 1:50,000 for larger ones. The second ones focus on the land use for a smaller geographical area, usually with a scale of 1: 5,000 or 1:10,000, and are used for areas where development is expected, or to avoid a future development. Decisions regarding the buildings' typologies, height and size, aesthetic qualities, etc., are included. Plans for smaller parcels of land, often encompassing just a few pieces of real estate, are called *Detailed Land-use Plans*. The municipality, as well as private individuals, developers, and organizations, can propose a Detailed Land-use Plan but experts such as urban planners and architects formulate the final plan. Moreover, two other laws influencing urban planning primarily in urban areas can be highlighted. The *Cultural Heritage Act* (Ministry of Climate and Environment Norway, 1978) protects archaeological and architectural monuments and sites, as well as the cultural environment, while the *Neighbors Act* (Ministry of Justice and Public Security Norway, 1961) regulates the relationships between adjacent properties, establishing restrictions on activities within one's property that may impact neighbors. Finally, other laws important in determining land use are the *Biodiversity Act* (lovdata, 1930) that concerns the conservation of nature, the protection of species and other environmental issues, and the *Agricultural Act* (lovdata, 1995) which fucuses on rural areas and it tries to preserve agricultural land from urban sprawl.

3.2.4 Sweden

Sweden is a unitary country with three levels of government: the national level, 21 counties and 290 municipalities. On the national level, a legislative framework (Figure 6) defines the system of land-use planning and provides guidelines that municipalities must follow in their plan-making process. The national legislation also defines the building code and designated areas that are strictly protected from development for nature or heritage protection. At the regional level, the County Administrative Boards represent the national government's interests in the planning process, with respect

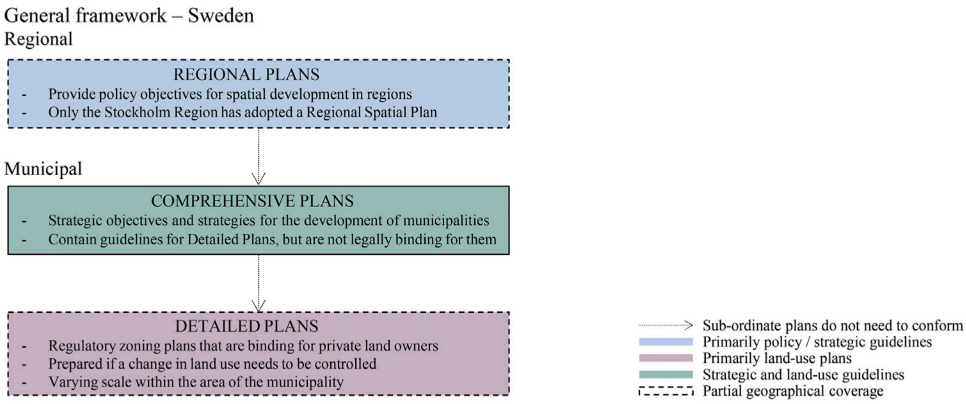

FIGURE 6
General framework, Sweden. Adapted from (OECD, 2017).

to the guidelines stated in the Planning and Building Act. Furthermore, they provide municipalities with data and advice and they co-ordinate municipalities in the case of conflicts. National legislation makes regional spatial planning obligatory for the Stockholm region, but not for other Swedish regions. Although no regional spatial plans exist outside of the Stockholm region, the government requires that there is a regional development strategy in each county. This strategy may contain spatial elements and influences land use decisions.

Municipalities have three main responsibilities related to land use:

- Local planning: developing Comprehensive Plans and Detailed Plans and issue building permits based on those plans and other relevant regulations.
- Public housing: providing housing through public housing companies, which constitute a significant share of all rental accommodation in Sweden.
- Technical infrastructure: ensuring the technical infrastructure required to develop land, such as roads and water and sewage disposal networks.

In Sweden, local authorities hold a planning monopoly, granting them exclusive rights to determine land use within municipal borders, often owning significant land in larger developments, thus serving both as planners and legal property sellers.

First in the process, a municipal comprehensive plan (a plan without legally binding impacts) is developed. Then, a detailed development plan is ordered by the political administration of the city and is developed by the urban planning department of the municipality (Lundström et al., 2013), where the use of land and water areas, built environment and construction works can be regulated. This is similar to a zoning plan as seen in other countries. The detailed development plan cannot conflict with the comprehensive plan. Local authorities must follow national legislative frameworks on, for instance, what to set in the detailed development plan, but they are free to design how new urban districts will look like. What a detailed development plan can or should contain is regulated in the Planning and Building Act (The Swedish National Board of Housing, Building and Planning, 2016).

3.2.5 Switzerland

Switzerland is a federal system structured into three institutional levels: National, Cantons (that correspond to states in other countries), Municipalities (Figure 7). The Confederation is responsible for basic legislation (Federal Act on Spatial Planning). This law defines the guidelines for implementing land use plans at all scales. The Confederation also has areas of competence through *conception and sectoral plans* concerning agriculture, military infrastructures, high voltage electricity grids, transport, and nuclear waste storage. As a federal system, each canton develops its own laws to implement the federal laws in different areas like land use planning and energy. Therefore, regulations are not uniform and vary from one canton to another. According to the Federal Act on Spatial Planning (art. 8), cantons are responsible to elaborate a *canton master plan* every 15 years that gives the main strategic orientations of land use planning for the next decade. The master plan of the Canton of Geneva is a good example (Office of Urban Planning, 2021). The larger cantons are structured into regions, each of which must also draw up a *regional master plan*.

Urban planning at lower level (municipal and local urban projects) should conform to the canton and region (if applicable) master plans and contribute to implementing them. Responsibility for urban planning and building depends on the cantons. In the urban canton of Geneva responsibility is mainly centralized by the Canton that adopts urban plans and building projects, whereas municipalities are only consulted. In other cantons (wider and more rural), municipalities have more decisional power and generally give final authorization to plans and projects.

At the local level, planning and building process generally follow the given steps from neighborhood to building level. Firstly, any neighborhood project may require a preliminary modification of the zone, especially when its classification is not suitable for the intended purpose, such as a transition from agricultural to a building zone. The planning of large neighborhoods involves the development of a *local master plan* by the Municipality or the Canton, outlining the key strategies and orientations for the area's transformation. Subsequently, the neighborhood is divided into plots. Property owners then collaborate to create a *local urban plan* for each

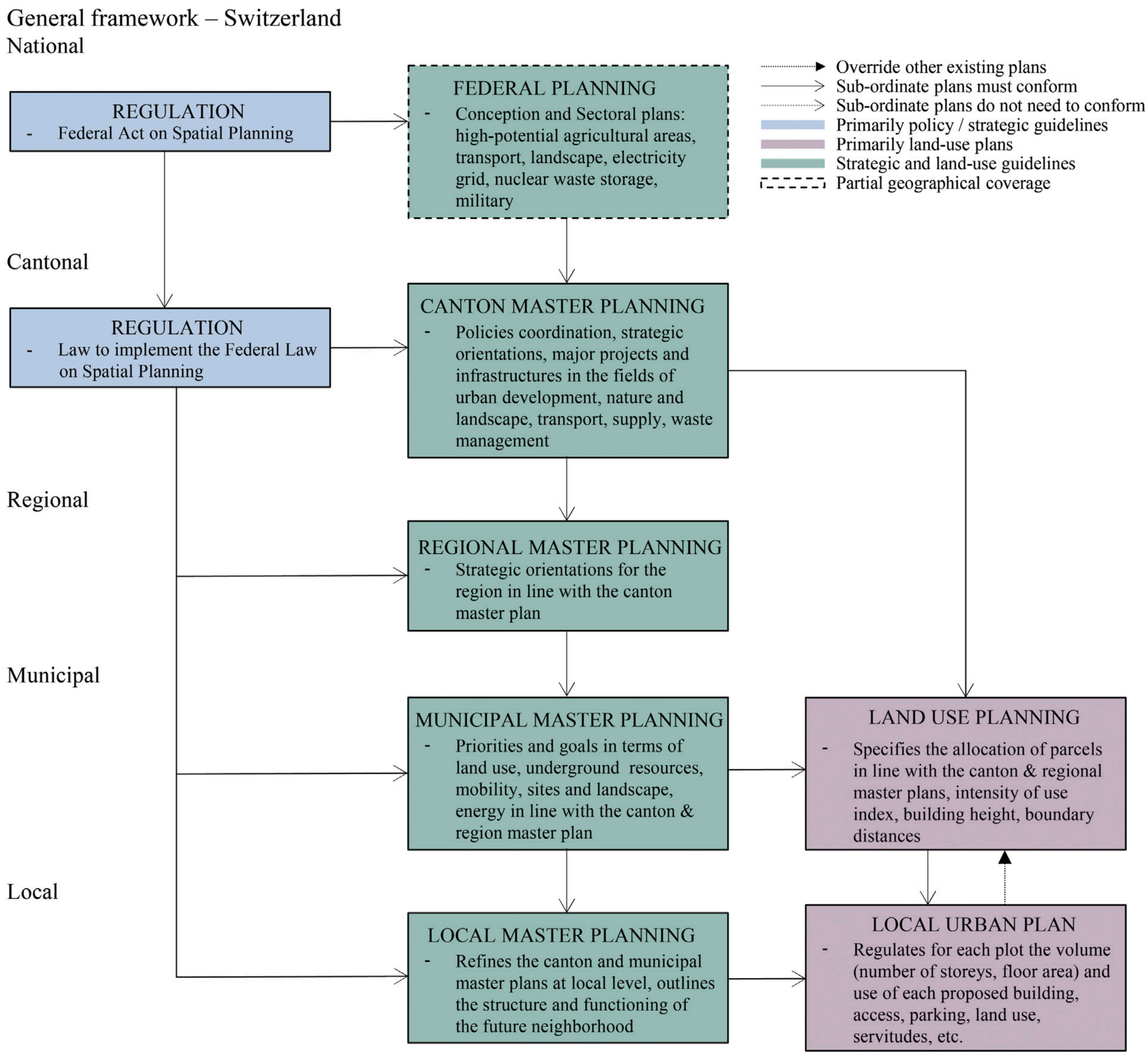

FIGURE 7
General framework, Switzerland. Adapted from (OECD, 2017).

plot, specifying details such as building implementation, facilities, infrastructures, built areas, and land use. In the case of smaller neighborhoods, a local urban plan is developed directly without the need for a master plan. Finally, architectural and building projects are designed by the housing estate. The zone modification and plans are then adopted by the Canton or the Municipality, depending on the specific regulations of the respective cantons.

At each local level (from neighborhood to building), energy concept is generally compulsory (together with other concepts on mobility, water management, noise, etc.) so as to integrate in planning and building strategies and measures on energy efficiency and renewable energy sources (RES) use. Finally, it is worth mentioning that Switzerland is characterized by a direct democratic system. Therefore, individuals have the possibility (by collecting enough signatures) to organize referendums against urban projects at municipal or cantonal level. (Land-use Planning Systems in the OECD, 2017).

3.3 Building regulations

Regarding urban development and construction, various nations demonstrate distinct strategies and priorities in their building regulations. These regulations cover a broad range of regulated aspects, from safety and technical compliance to aesthetic and environmental concerns.

3.3.1 Canada

In Canada, regulations of urban developments may encompass different aspects of public and private buildings. Specific regulations are in place according to building types, whether residential or commercial. Various cities have additional regulations related to specific urban structures. For example, the City of Calgary dictates the architectural designs of bridges, reservoirs, and transit stations. Other cities have developed strategies and guidelines for specific developments (e.g., hillside developments).

A survey of details being regulated on building and urban design levels was carried out. Four categories were used in the survey: building, site and neighborhood levels and public spaces. At building level, the most regulated aspects include height, material, massing roof design, windows, and entrances. At the site level, landscaping, signage, parking, site circulation, lighting, and site services. At the neighborhood level, streetscape, heritage resources, views and vistas, parks and open areas, trees and woodlands, street network and transit stops. In terms of public space, regulated elements include sidewalks, landscaping, signs, lighting, servicing, street amenities, on-street parking, public arts, and street corners. The least amount of emphasis seems to be on the public realm.

3.3.2 Italy

At the municipal level, two main legislative instruments contain specific provisions for the construction of buildings and neighborhoods: the PRG and its Technical Implementing Regulations (NTA), and the Building Code. The purpose of the PRG (i.e., the main municipal urban planning instrument) is to: (i) define the intended use of each part of the municipal territory and the relevant urban regulations with reference to the existing environmental conditions and the needs of the population, (ii) specify the constraints to be respected in urban and building transformation activities, (iii) define the zones for urban development and the related requirements, and (iv) establish the discipline for interventions in existing urban areas. Mandatory regulated aspects of the PRG include the definition of the communication network and related facilities, the zoning of the municipal territory, public areas, constraints to be respected in areas of historical, environmental, or landscape value. The NTA are an integral part of the PRG and detail the programmatic forecasts and zoning. They contain, e.g., prescriptions and quantitative limits for building parameters for each zone or building (i.e., geometric parameters, such as building density per each area, building height, etc.), permitted uses, distances between buildings, and other constraints to be respected. While the NTA provides a detailed description of the building parameters and construction requirements and with reference to each zoning, going as far as to provide precise references for each building, the Building Code regulates the administrative aspects of the process. It is a regulatory instrument used by each municipality to control the construction of buildings, ensuring compliance with the technical-aesthetic, sanitary, safety and habitability requirements.

3.3.3 Norway

Almost every aspect of urban planning is regulated in Norway. In that sense, the most important regulatory instrument is the zoning plan, operating on a scale between 1:5,000 to 1:10,000. The plan includes provision regarding the following aspects: (i) design aesthetics, land use conditions, prohibited types of use and building limits; (ii) pollution thresholds and environmental quality requirements; (iii) functional and quality standards for buildings and outdoor areas in connection to health, safety and universal accessibility; (iv) number of dwellings and size; (v) historical buildings, cultural monuments, and natural assets preservation; (vi) traffic management measures and parking, including upper and lower limits for parking coverage; (vii) land use distribution and detailed zoning, including definition of areas to be set aside for public use (Environment, 2008). Moreover, a particular attention can be found in the Norwegian regulation when it comes to safety against natural threats such as floods, storm surges, terrain prone to erosion, and all types of landslides. Specific risk areas are determined and new constructions in these areas must be carefully weighted according to their functions. General considerations are also given for designing in wind-exposed areas, especially in relation to fastening the roof materials not to cause potential damages to people, animals, or equipment. Additionally, regarding ice and snow, the buildings must be designed in a way that slides from roofs or terraces do not cause risks for areas (e.g., sidewalks, roads, outdoor areas) where people normally live (Byggkvalitet, 2017).

3.3.4 Sweden

There are different aspects regulated regarding urban development and construction in the detailed development plan. The most important terms used in the detailed development plan to describe the geometry of buildings are building function, building footprint, street layouts, building height, ridge height, total building height and roof inclination. On the neighborhood level, road and communication network, building density, parking spaces, and reserved areas for public spaces and buildings. Previous detailed development plans are still valid concerning heritage restrictions.

3.3.5 Switzerland

Every aspect of urban planning and building is regulated in Switzerland with some variations depending on the cantons:

- Zoning: building projects can only take place in zones dedicated to this use (as defined in master and zoning plans at canton and municipal level), with very few actions margin now to declassify unbuilt areas.
- Heritage: in Geneva for instance, almost every building is registered in term of heritage quality. Therefore, many buildings are classified, not necessary the oldest one, which limit refurbishment and solar installation potential.
- Mobility: norms give recommendation for the number of parking places for bicycles (1 place/room) and cars. Parking spaces also depend on the localization of the building project regarding to public transportation accessibility. In downtown, the ratio parking place/flat is generally less to one.
- Building height and density: it depends on the localization relatively to downtown and the type of building zone, which limits the ratio building/plot surface and the height.
- Building code including insulation, ventilation, and energy. Regulations are based on the norms edited by the Swiss society of engineers and architects (SIA) that should be met as a minimum, adding other requirements for some aspects.

4 Solar and energy efficient neighborhoods

This section summarizes some of the regulations, standards, and codes for designing solar and energy efficient neighborhoods. Different countries have approached solar access in urban areas and neighborhoods in different ways, as discussed below. Initiatives to achieve net zero energy neighborhoods are being introduced in many countries. Such initiatives rely heavily on the integration of high energy performance criteria and solar energy technologies.

4.1 Solar and energy performance regulations

Countries are increasingly implementing codes and standards for energy efficiency. Some of these standards and codes include specifications for the use of solar energy for passive heating and daylighting to reduce energy consumption.

4.1.1 Canada

The federal system encourages in general the implementation of solar energy, and reduction of energy consumption, but it has not produced any specific legislation addressing solar access.

Regarding energy efficiency, several codes and standards are starting to appear in the last decade, some of these are specific to provinces in Canada (or even specific cities and jurisdictions) while others are national. Nevertheless, most standards are still based on building-scale. Some of the solar related initiatives and energy efficiency standards and codes include initiatives such as The City of Toronto Official Plan which states that new development in existing neighborhoods must allow for the provision of sunlight and views of the sky for the residents. This should be achieved by "ensuring adequate distance and separation between building walls". Similarly, apartment neighborhoods must "maintain sunlight and comfortable wind conditions for pedestrians on adjacent streets, parks and open spaces" (Official Plan – City of Toronto, 2024). Another example is the Town of Millet (AB, Canada) (Centre, 2019) which introduced the right-to-light through their municipal bylaws. This bylaw effectively ensures access to solar energy for solar panel installations on individual properties.

Some guidelines that support the installation of solar technologies are developed. Examples include the Solar Ready Guidelines by the National Resources Canada (Natural Resources Canada, 2013), where builders are required to meet various elements of Solar Ready Guidelines in accordance with the National Building Code of Canada, the National Plumbing Code of Canada, Canadian Electrical Code, Part 1 including provincial/municipal provisions. Another example is the Photovoltaic Ready Guidelines developed by Canmet Energy Research Centre (Natural Resources Canada, 2019), which highlights that builders must ensure that all elements related to the Photovoltaic Ready Guidelines are completed in accordance with the building and electrical codes and regulations that apply at the building site.

The greater use of solar energy is promoted through financial incentives, tax credits, and grants. For example, the Investment Tax Credit (ITC) in Canada is a refundable incentive mechanism that allows eligible enterprises to receive a tax credit, which can amount to up to 30% of the capital investment made in renewable energy initiatives, including but not limited to solar power systems (Canada Revenue, 2024).

4.1.2 Italy

The Italian national legislation promoting energy efficiency and the diffusion of renewable energy has been developed as an implementation of the main European directives (Ministry of Economic Development, 2020).

At the national level, the Integrated National Energy and Climate Plan, adopted in 2020, has set some growth targets for electricity and thermal energy from renewable sources (Ministry of Economic Development, 2020). These targets are pursued by the Italian regions, which can increase the minimum quota or specify the renewable energy systems to be used. Furthermore, the "Renewables Decree" (D.Lgs 28/2011) (Italian Republic, 2011) requires the integration of renewable energy sources (RES) in new buildings or buildings undergoing major interventions. Indeed, in the case of new construction, renovation, or demolition and reconstruction, RES should cover 50% of the Domestic Hot Water (DHW) consumption, and 50% of the sum of consumptions for DHW, and space heating and cooling. For public buildings the share is increased to 55%; while for private buildings located in historic city centers the share is reduced to 25% (27.5% for public buildings).

Within the European framework and under the Covenant of Mayors, municipalities have adopted two key legislative tools, the Sustainable Energy Action Plan (SEAP) and the Sustainable Energy and Climate Action Plan (SECAP), to facilitate local sustainable energy policies and climate change mitigation by minimizing fossil fuel use (Santopietro and Scorza, 2021). Numerous Italian cities have formulated mitigation plans and embraced decarbonization strategies (Kona et al., 2019).

Municipal requirements for active Solar System installations, influenced by national standards, vary, mandating PV technologies, ST collectors, or both, depending on urban characteristics, with historic centers typically imposing stricter regulations. The Italian government incentivizes sustainable practices through tax benefits for energy efficiency and renewable energy installations, offering up to 90% deductions for building retrofits and combined PV and storage systems installations with efficiency measures (e.g., insulation, air conditioning).

Regarding passive solar strategies, minimum daylight levels in buildings are regulated by national legislation (Appolloni et al., 2020). These set the minimum level of daylight factor depending on the type of building, as follows:

- Residential buildings: ≥2%; the total window surface area that can be opened must not be lower than 12.5% of the total floor area;
- Hospitals and schools: ≥3% (rooms and labs), ≥2% (gyms and canteen), ≥1% (offices and other service rooms).

In general, the minimum requirements vary depending on each municipality. However, regarding window area, there are some common standards for residential and non-residential buildings. In the first case, each primary room (i.e., room in which the occupants are permanently present) must have a window area not less than 1/8 of the floor area, with a derogation to 1/12 for attic rooms where lighting is provided by flat or semi-flat windows (e.g., skylights). For non-residential buildings the window area must be at least:

- 1/8 of the useable surface (SU), if the area of the room is less than 100 m^2;
- 1/10 of the SU, with a minimum of 12.5 m^2, if the surface of the room is between 100 and 1,000 m^2;
- 1/12 of the SU, with a minimum of 100 m^2, if the surface of the room is greater than 1,000 m^2.

There are no daylighting requirements for the building stock at the national level; while some regional laws (e.g., Lombardy) require designers to ensure an adequate level of visual comfort by considering the use of daylight and its integration with artificial lighting sources (Kunel et al., 2015).

4.1.3 Norway

In Norway, the government encourages the use of renewable energy sources and low energy solutions to be integrated into new and existing developments. Nevertheless, a specific framework that regulates the use of solar energy in an urban environment is still missing. Recently, several regulations and reports have addressed the problems related to the right of the view and daylight in urban context, as well as the esthetical and technical integration of solar systems in buildings. Most of them refer mainly to the building scale, however the focus on the larger scale is progressively growing. The most important national regulation when it comes to energy efficiency in buildings is the Building Technology Regulation TEK17 (Direktoratet for byggkvalitet, 2017), defining the minimum functional, technical and performance requirements for construction works to be legally approved in Norway. Regarding outdoor solar accessibility, recreational areas must be designed and located so that good solar conditions are achieved. When this is not possible for the entire area, the placement of sedentary activities (e.g., seating, social meeting places) in favorable sunny conditions is recommended. An additional guidance, advising common outdoor areas and housing units to be exposed to direct sunlight for a minimum number of hours every day between the two equinoxes and a minimum distance between adjacent buildings, was repealed from TEK17 in 2021 with the purpose of allowing local municipalities to set specific requirements based on local conditions. When discussing indoor visual comfort requirements, TEK17 distinguishes between "light" and "view", providing requirements for both. In general, daylight requirements can be met by achieving an average daylight factor of 2% for the most critical room. Alternatively, equations 1 and 2 can be used for rooms in housing units and holiday homes respectively if nothing screens the view of the horizon at an angle of more than 45° measured from the horizontal plane. In equations 1 and 2, A_g is the glass area facing the open air which is placed at a minimum of 0.8 m above the floor, A_{BRA} is the room's useable area, including outdoor areas under overhead balconies or cantilevered parts, τ and is the visible light transmission of the glass.

$$A_g \geq 0.07\, A_{BRA} \big/ \tau \quad (1)$$

$$A_g \geq 0.1\, A_{BRA} \quad (2)$$

Regarding view out, each room for permanent stay is required to have a window providing a satisfactory view, meaning a good contact with the outdoor, or a view to other urban elements (e.g., rows of houses, streets, backyards) in case of densely built-up areas (Direktoratet for byggkvalitet, 2017). The installation of active solar systems within cities is regulated through national standards such as the Neighbors Act (Ministry of Justice and Public Security Norway, 1961) and the Planning and Building Act (Plan-og bygningsloven, 2008). The first is more general, setting tolerance limits on individual activities within a property if they impact neighboring ones. The second classifies solar cells as technical installations, therefore requiring approval from the municipality. However, in accordance with SAK10 (Direktoratet for byggkvalitet, 2011), the installation of PV cells is allowed without formal approval from public authorities, provided they adhere to the municipality's plans, meet all technical requirements in terms of water/air tightness and structure integrity, and are situated within a single utility unit or fire cell. Despite that, municipality plan can sometimes be particularly stringent, as for the *Kommuneplan for Stavanger 2014–2029* (Stavanger Kommune, 2015) where specific guidelines to protect Europe's largest contiguous wooden house development are provided. In this example, any construction work that modifies alters the appearance of buildings must be reported to the municipality. The replacement of original building elements (e.g., windows, doors, façade and roof cladding) is only allowed if the new components align with the house's original style and material, provided that the existing elements no longer meet technical requirements or are irreparably damaged. These stringent guidelines pose challenges for the integration of solar systems into the neighborhoods. A notable instance in 2019 exemplifies the difficulty, wherein the municipality compelled the removal of a solar system installed on the roof of a private house. Particularly relevant are regulations that define plus-customer as a customer who both produces and consumes electricity with a limit of power at the connection point of 100 kW (lovdata, 1999). Plus-customers are exempt from paying network rent and fees from consumption that is covered by self-produced electricity. The plus-customer scheme was expanded to properties with several electricity subscribers, in October 2023. This change allows participation in energy sharing initiatives involving installations of up to 1 MW within the same property. Finally, a support scheme for the installation of photovoltaic systems in private households is also available in Norway through ENOVA, a governmental enterprise promoting the environmentally friendly production and consumption of energy. A fixed economic support is granted for the installation of solar systems, while a proportional one is guaranteed based on the power capacity of the system, up to 20 kWp. Additional economic support is achievable by combining electricity generation with other energy measures, such as ST collectors or energy storage systems.

4.1.4 Sweden

In Sweden, municipalities may determine 'the extent of the built environment above and below the ground surface, the use of the buildings, the proportion of apartments of various types in dwellings, and the size of the apartments (The Swedish National Board of Housing, Building and Planning, 2016). This can affect significantly the future deployment of solar energy concepts and their application. Additionally, the detailed development plan established by the municipalities 'must be designed with reasonable consideration to the existing built environment, property rights and real property units that could affect implementation of the plan'. This might influence future disputes about already existing solar energy systems where future property development might influence the production of such a system.

Another important factor is that the detailed development plan cannot prescribe the use of a specific technology, e.g., it cannot state that future real estate developers must install PV/ST systems on buildings (The Swedish National Board of Housing, Building and Planning, 2016).

The geometrical description of building in the detailed development plan is also important to consider since this affects the conditions for the installation of solar energy (Kanters and Wall, 2018) besides determining the function of the planned buildings, vegetation, and use of public space. Key terminology employed in the comprehensive development plan to outline the geometric characteristics of buildings includes the building footprint, building height, ridge height, overall building height, and roof pitch.

The geometry described in the detailed development plan could have a direct effect on the performance of future solar energy systems installed in the area. The orientation and roof inclination determine where solar energy systems could potentially be installed, but the other parameters–mostly of the surroundings-could have a great impact on the performance of a solar system due to the shading impact of buildings.

Subsidies for PV installation and batteries are available in Sweden. For house owners of residential buildings, with some limitations, the cost (work and material) of installing a grid-connected PV-system is reduced with 20%. The installation of batteries as storage for locally produced electricity gives a cost reduction of 50% (work and material).

4.1.5 Switzerland

In Switzerland, energy transition is driven by the Swiss Energy Strategy 2050, which aims at progressively phasing out from nuclear energy production by massively increasing electricity production from renewable energy sources (e.g., hydro, solar, wind), and improving energy efficiency in buildings. This Strategy was approved by the Swiss population in 2017 and is being implemented through the revised Federal Act on Energy (Swiss Federal Office of Energy SFOE, 2021). Energy regulations are currently evolving at all institutional levels to meet the climate engagements toward 2050. At Federal level, In June 2023, the Climate Act was adopted by the population, requiring Switzerland to achieve net-zero carbon emissions by 2050. To reach this goal, the Swiss government will allocate 3.2 billion CHF over a span of 10 years to support building owners in transitioning away from fossil energy sources for heating and to encourage companies to invest in climate-neutral technologies.

The Swiss legislation through the Energy Strategy 2050 and the Federal Act on Energy promotes the intensification of solar power production on building roof and facades. Federal subsidies enable to cover up to 30% of the investments. The economic model is based on own consumption of the electricity produced inside the building. Indeed, the resale price of solar electricity to the grid is generally lower than the cost price of the solar installation. Therefore, the own-consumption rate is higher provided the solar installation is combined with a heat pump system.

Another important aspect of the Federal Act on Energy is the promotion of self-consumer communities not only at the scale of the building but also at the scale of the whole neighborhood. This implies having only one purchase point for the community on the grid for selling and buying the power. As the electricity market is free only for consumption higher than 100′000 kWh/year, this regrouping enables the community to have access to this market with preferential prices. The Swiss Federal Office of Energy (SFOE) also published a guideline on communities of solar PV own consumers (The Swiss Federal Office of Energy SFOE, 2019).

4.2 High energy performance codes

This section highlights some of the main energy performance codes that are currently in force in the five countries considered.

4.2.1 Canada

Several energy efficiency codes and standards are being developed in Canada to encourage energy efficiency in buildings and as method to reduce carbon footprint of the building environment. The National Energy Code for Buildings (NECB), Canada (National Research Council Canada, 2020), is the main nation-level that regulates energy efficiency of buildings.

The national model building code system was incorporated within the Pan Canadian Framework (PCF) on Clean Growth & Climate Change. Under the PCF, signed in 2016, the federal and provincial governments (excluding Saskatchewan) are committed to a net zero energy ready model national building code by 2030.

In addition to these two national codes, there are several provincial incentives. For example, the British Columbia (BC) Energy Step Code (Government of British Columbia, 2017) is an initiative directed toward high performance developments exceeding BC Energy Code. To comply with the BC Energy Step Code, builders must use energy software modelling and on-site testing to demonstrate that both their design and the constructed building meet the requirements of the standard.

4.2.2 Italy

The European nZEB standard sets high performance levels for all new buildings or those undergoing major renovation, from 1st January 2021. The nZEB concept was introduced at European level in 2010 (European Union, 2010), and was transposed into Italian law in 2013. The characteristics and standards (e.g., thermal performance, heat exchange coefficients, etc.) of nZEB in Italy are defined by the Ministerial Decree of 2015 (Ministry of Economic Development, 2015). The decree defines two sets of limit values for the thermo-physical characteristics and efficiency of the building and its mechanical, electrical and plumbing components; one valid until 2021 (2019 for public buildings) and a second, more restrictive, valid from 2021. Some regions and autonomous provinces have also anticipated the 2021 deadline. For new buildings, nZEB requirements have been mandatory in Lombardy since 2016 and in Emilia Romagna since 2017 for public buildings and 2019 for others.

4.2.3 Norway

Besides the national technical regulation TEK17 (Direktoratet for byggkvalitet, 2017) there are two other Norwegian standards for high performance buildings: (1) *NS 3700:2013 Criteria for passive houses and low energy buildings –Residential buildings*, and (2) *3701: 2012 Criteria for passive houses and low energy buildings–Commercial buildings*. Norway is the only European country with its own passive house standard, however, taking the requirements for passive houses from the German Passive House Institute (Passivehouse, 2023) as a basis for it.

Moreover, the outcomes of the Zero Emission Building Research Centre (ZEB, 2021), and the Zero Emission Neighborhoods in Smart Cities Research Centre (FME ZEN, 2021) are worth to be mentioned. Although they do not represent official codes or standards, they provide valuable guidance and key performance indicators to design high-performing buildings and neighborhoods.

4.2.4 Sweden

The current Swedish building regulations put requirements on the maximum amount of energy that can be used per floor area and year, expressed as primary energy, in line with the European goal to minimize the energy used within the building sector. This includes space heating, cooling, DHW, and common electricity. Besides the maximum annual energy required for space heating, cooling, DHW and common electricity, the building regulations also stipulates the maximum power need for space heating and the maximum average heat transfer coefficient for building parts and thermal bridges. The building regulations also stipulate daylight criteria that must be met for new buildings.

The energy produced by PV or ST on buildings can be deducted from the calculated amount of the building's energy need. A building permit is not always required when installing solar energy systems on existing buildings, but always on new buildings.

4.2.5 Switzerland

During the last decade, Swiss cantons have been enacting ambitious energy laws and regulations in application of the Federal regulations (MoPEC, 2015). For example, energy regulation is particularly ambitious in Geneva. Every new building should meet the requirements of the High-performance standard (called HPE) as a minimum legal. This standard is 20% more ambitious than the SIA building code in terms of heating efficiency for instance. The very high-performance standard (called THPE) is even required for public buildings. However, private owners can also adopt such a standard on a voluntary basis. HPE and THPE standards are also applied for retrofitted buildings below (Département du territoire DT - Office cantonal de l'énergie, 2019) summarizes the requirements of the HPE and THPE standards in Geneva in terms of energy efficiency and solar installation for both new and retrofitted buildings. The Canton of Geneva through its energy master plan 2020–2030 (Cantonal Energy Office Geneva, 2020) expects to limit the heating consumption of existing building up to 125 kWh/m^2/year by 2030, which involves for many buildings to develop ambitious retrofitting strategies. Furthermore, heating systems that rely on fossil fuels and have reached the end of their operational life should be replaced with renewable energy-based systems, such as heat pumps. The Canton of Geneva through its energy master plan 2020–2030 (Cantonal Energy Office Geneva, 2020) expects to limit the heating consumption of existing building up to 125 kWh/m^2/year by 2030, which involves for many buildings to develop ambitious retrofitting strategies. Furthermore, heating systems that rely on fossil fuels and have reached the end of their operational life should be replaced with renewable energy-based systems, such as heat pumps.

4.3 Common practices

Common practices in the studied countries are presented below.

4.3.1 Canada

Common practices are starting to emerge in various areas of Canada (and North America) to accommodate more sustainability related designs. These are mostly encouraged by voluntary standards and certificates that treat various aspects of the built environment, including energy efficiency and renewable energy. A summary of some of these common practices is presented below.

- LEED for Neighborhood Development (LEED-ND) (2009) includes numerous point-based sustainability criteria, and has four levels of certification (i.e., platinum, gold, silver, and certified) (Uda and Kennedy, 2018). It covers a range of sustainability issues, including healthy environment, pollution and risks, water efficiency and waste management, energy efficiency, ecology, sustainable sites, management and quality of service, economic aspects, and community (Uda and Kennedy, 2018).
- ASHRAE/ICC/USGBC/IES Standard 189.1–2017, Standard for the Design of High-Performance Green Buildings (ASHRAE, 2017) is focused on building level but it can strongly influence the overall neighborhood design. Various sections include site sustainability, water efficiency, energy efficiency, indoor environmental quality, material and resources, and construction and plans for operation.
- ANSI/GBI 01–2019: Green Globes Assessment Protocol for Commercial Buildings (Assessment System) (Green Building Intiative, 2019). This standard provides a method for evaluating commercial buildings with respect to contemporary best practices for high-performance green buildings. The six areas of assessment within the standard include project management, site, energy, water efficiency, materials, and indoor environment.
- Building Research Establishment Environmental Assessment Method: Green building rating and certification system include on-site independent third-party inspection for new construction, in-use, refurbishment and fit out, communities, and infrastructure.
- NZEB Certification (International Living Future Institute, 2021): certification program for NZEB using the structure of the Living Building Challenge which can be applied to any building type.
- Passive House Institute US (EcoHomes, 2020): Performance based passive building standard in terms of air tightness requirement, source energy limit, and space conditioning criteria.

4.3.2 Italy

In Italy, common practices that support the diffusion of solar policies and high-performance standards in urban areas include energy performance certificates, and voluntary certifications.

Currently, Energy Performance Certificates (EPCs) are mandatory for all types of property being constructed, sold or rented out to a new tenant, for new buildings and for buildings with a total useful floor area of less than 1,000 m^2. The Italian EPC has a standard format valid throughout the country and is structured to provide simple and clear information on the efficiency, performance and energy requirements of the building and its thermal systems (ENEA, 2020). The certificate includes, among others, information on the overall energy performance in terms of both total primary energy and non-renewable primary energy, the energy class (A4 to G) determined based on the total non-renewable energy performance of the building, and carbon dioxide emissions.

Voluntary certifications for the energy efficiency and sustainability of buildings include several national and international standards:

- CasaClima: introduced in 2002 b y the Autonomous Province of South Tyrol as energy certification system for buildings (Agenzia CasaClima, 2021) The certification is compulsory for all new buildings in South Tyrol, while in other parts of the Italian territory it is adopted on a voluntary basis.
- ITACA: Italian environmental certification, developed in 2011 on the basis of the American Green Building Council (Protocollo ITACA, 2011)
- ARCA: certification for wood constructions (ARCA Certification, 2023)
- LEED: based on the general international certification protocol, the local Green Building Council has also developed a certification system targeted specific to the Italian context (Green Building Council Italia, 2009)
- Other international standards (e.g., BREEAM, WELL, and PassivHaus).

Some certifications also recognize the social, environmental and economic sustainability at the neighborhood level, such as the LEED protocol "GBC Quartieri" and WELL for Community. At present, very few Italian neighborhoods have obtained one of these certifications; the most famous example is the Porta Nuova district in Milan (The plan, 2022).

On a broader scale, White certificates are the most important energy efficiency promotion scheme in Italy. The scheme is based on the obligation imposed on distributors of electricity and natural gas with more than 50,000 domestic and non-domestic customers to achieve quantified annual energy savings targets (Toro et al., 2022).

4.3.3 Norway

Some of the common practices employed in the design of solar and high-energy performance neighborhoods are summarized below.

- SINTEF Building Research Design Guides (SINTEF, 2021) is a collection of solutions and recommendations dealing with design, construction and management of buildings developed by SINTEF Community. It includes three sections: Planning, Construction details, and Building Management. Some of the reports are relevant regarding daylight level and shading devices, planning regulations, and integration of photovoltaic systems into buildings and constitute starting point for the development of national legislations on these topics.
- RIF Daylight in buildings (RIF, 2020) represents a guide for natural daylight accessibility in buildings and it summarizes the Norwegian construction industry experience with TEK17 in terms of daylight requirements. The Vertical Sky Component metric to assess daylight accessibility at the early stage of the design process, as well as thresholds to evaluate it are proposed. Moreover, an alternative approach to the one utilized in TEK17 to evaluate indoor daylight is also introduced.
- FutureBuilt is an innovation programme started in 2010 which aims to exceed the UN Sustainable Development Goals and Paris Goals, and always cut greenhouse gas emissions by at least 50% compared to current regulations and normal practice. Several Norwegian municipalities support the scheme, and 71 projects have already been realized by June 2023. Among the topics covered by the FutureBuilt criteria are climate and energy, social sustainability, circular buildings and districts, biodiversity, climate adaptation, green mobility, architecture qualities.
- Nordic Swan Ecolabel introduces requirements on various aspects of buildings including energy use, chemical products, building materials, and indoor environmental factors to promote health and environmental sustainability.
- BREEAM-NOR is the national adaptation of the international BREEAM certification system for buildings.
- Other international certifications (e.g., LEED, WELL).

4.3.4 Sweden

In Sweden, a growing number of buildings are aiming to achieve (voluntary) building certificates. Larger municipalities and cities have different practices when it comes to the planning of high-energy performance neighborhoods.

- There is one certification scheme aimed for the planning of sustainable neighborhoods, which is called CityLab (Sweden Green Building Council, 2023).
- Larger cities are likely to have routines in place to ensure that daylight requirements will be met later in the design phase. For instance, the city of Malmö first determines the obstruction angles in the neighborhood, analyze the Vertical Sky Component for critical points, and a more advanced analysis is performed in a later stage (Kanters et al., 2021).

On the building level, the following buildings certification schemes are used as common practice:

- Miljöbyggnad is a Swedish system for building certification. Local production of renewables is encouraged and rewarded with points.
- NollCO2 is another certification to reduce the environmental impact of buildings, where the production of renewables is awarded and included as well.
- International certifications that are adapted to the Swedish context, like BREEAM-SE and LEED.

4.3.5 Switzerland

In Switzerland each canton has developed its own energy regulations, all geared towards meeting federal goals on energy and climate transition by 2050 (achieving net-zero carbon emissions). Aligned with these goals, common practices are implemented at all levels and stages, ranging from municipalities to building projects.

The first aspect of these common practices is normative. All projects, whether new developments or renovations, are based on the Swiss building codes published by the Swiss Society of Engineers and Architects (SIA). These codes address energy efficiency in buildings, encompassing heating, ventilation, electricity, and cooling. On this basis, the Conference of the Energy Departments of the cantons reaches a consensus on a common energy regulation framework (MoPEC, 2015). This framework serves as a reference for the elaboration of cantonal energy laws and building projects.

The second aspect involves the application of energy labels at all scales—municipality, neighborhood, and building—in accordance with SIA and ENDK norms. These labels, endorsed and promoted by the Confederation and the cantons, are managed by private-public organizations. The Swiss labels include:

- The Cantonal Energy Certificate for Buildings (CECB, 2024), which provides an energy label (A to G) for existing or project buildings. It assesses building envelope efficiency, global energy efficiency (heating, cooling, electricity), and direct CO2 emissions.
- Minergie® (Swiss building standard - Minergie, 1998), the Swiss label for comfort, efficiency, and climate protection, applicable to both new buildings and renovations. It includes variations such as the basic Minergie label, Minergie P (more ambitious in terms of envelope insulation), and Minergie A (rewarding autonomy based on yearly production of locally produced renewable energies). The ECO complement, combined with one of the three Minergie standards, results in a particularly healthy, circular, and ecological building. The new label Minergie-Neighborhood (from end 2023) sets rules for planning or transforming neighborhoods into climate-friendly districts, focusing on energy, comfort, and mobility.
- SNBS-Building, a comprehensive concept for sustainable construction and renovation in Switzerland, covering the three areas of sustainability: society, economy, and environment. The label SNBS-Neighborhood SNBS - NNBS introduced in 2023 takes into account the site's location, quality of public spaces, circular economy, mobility, and governance.
- The "Cité de l'énergie®" (Energiestadt, 2024) label is awarded to a city or municipality that has made above-average efforts in its municipal energy and climate policy.

CECB, Minergie, and SNBS use the same base of energy balance calculation (weighted energy index per square meter considering energy use for supply). Solar energy plays a crucial role in this aspect. In the updated version Minergie 2023, solar panels are required to cover at least 60% of the roofs and facades in the case of buildings higher than three to four floors. Energy and carbon balances for construction and mobility are also considered by Minergie and SNBS. Private and international labels including LEED, BREEAM, DGNB are also utilized for building projects.

5 Discussion

This section presents the main observations of regulations in traditional neighborhood planning, as well as in energy efficient and solar neighborhoods. Recommendations for future actions to establish solar regulations are presented.

5.1 Overview and discussion of regulations

5.1.1 General neighborhood planning

In traditional neighborhoods, regulations are administered by different regulatory bodies in different countries. In Canada, municipalities take on a central role in implementing regulations, while in Italy, Norway, Switzerland and Sweden there is a hierarchical approach from the national to the municipal level. Regulatory approaches in different countries have unique characteristics. In Canada, regulations focus on land use, building design, and environmental regulations; these vary between municipalities. Italy operates within national and EU parameters with municipal plans, while Norway has a comprehensive approach, with Municipal Master plans, Zoning Plans, and Detailed Zoning Plans. Sweden uses the Planning and Building Act, and Switzerland implements federal legislation through cantonal regulations, emphasizing renewable energy planning at all levels. Regarding building-level regulations, Canada, Italy, Switzerland and Sweden all address building height and design, with Sweden also addressing orientation and glazing for solar gains.

Neighborhood level regulations in the countries address urban planning and infrastructure. This includes aspects such as streetscape, heritage resources, parks, and transit infrastructure in Canada. Italy and Norway focus on road and communication networks, building density, parking spaces, and designated areas for public use. Norway also implements regulations when it comes to safety against natural hazards, such as floods, landslides, and storm surges. In Sweden, a national framework legislation regulates land-use planning and provides guidelines for municipalities. Regional representation support municipalities in adhering to national guidelines. In contrast, Switzerland operates on a federal system with the national, cantonal (state), and municipal levels, allowing each canton to establish its laws in various areas, including land use and energy, leading to non-uniform regulations. All of the above countries also have regulations for the preservation of cultural and heritage buildings and neighborhoods.

A summary of the main traditional practices in the five countries considered is presented in Table 1. Key observations include that responsibilities for various urban planning regulations are shared between different levels of government in all countries. Designing for a specific climate is generally not well considered in all countries, although in some countries, such as Switzerland and Italy, local climate is relatively accounted for, through municipal climate plans (Switzerland) and SECAP (Italy).

5.1.2 Solar energy and energy performance

Solar regulations for neighborhoods differ among countries, but common themes emerge. Many countries, including Canada and Switzerland, emphasize energy efficiency and sustainability in these regulations, with a focus on optimizing sunlight access through building orientation. National and regional laws, often enforced by high-performance energy codes, promote solar adoption in these countries. In Canada, regulations include the National Energy Code and regional frameworks like the Pan-Canadian and BC Energy Step Codes. Italy enforces European nZEB standards for new or renovated buildings, covering thermal performance, HVAC efficiency, and thermal transmittance limits. Norway relies on a series of guidelines developed by research centres, such as the Research Centre on Zero Emission Neighbourhoods in Smart Cities and the Research Centre on

TABLE 1 Traditional practices in the design of neighborhoods.

Country	General regulations		Regulated aspects		
	Regulatory level	Key features	Building level	Neighborhood level	Cultural/ Heritage
Canada	• Municipalities	• Prioritize building design • Less emphasis on public realm • Regulations differ with the municipality	• Regulations by building type (residential or commercial) • height, material, massing roof design, windows, and entrances	• Zoning, bylaws, policies statement • Streetscape, heritage resources, views and vistas, parks and open areas, trees and woodlands, street network and transit stop	• Heritage preservation policies
Italy	• Hierarchical approach (National to Municipal levels)	• Municipalities can enforce regulations within national and EU parameters • Territorial Coordination Plan & General Regulatory Plans	• Heights, orientation, sun shading, and glazing • Minimum habitable room size	• Road and communication network • Building density • Parking spaces • Reserved areas for public spaces and buildings	• Constraints for areas of historical values
Norway	• Hierarchical approach (National, County, and Municipality)	• Municipal Master plans, Zoning Plans, and Detailed Zoning Plans	• Design constrains and aesthetic • Number of dwellings and size • Historic preservation	• Land use • Environmental requirements • Outdoor areas • Traffic and parking • Regulation against natural stresses (e.g., floods, landslides, wind	• Cultural Heritage Act
Sweden	• National level, County Administrative Board, and Municipalities	• Planning and Building Act	• Building height, ridge height, total building height, and roof inclination	• Road and communication network • Building density • Parking spaces • Reserved areas for public spaces and buildings	• Designates strictly protected areas for heritage preservation
Switzerland	• National, Cantons (corresponding to states in other countries), and Municipalities	• Each canton creates laws to implement federal laws in areas such as land use and energy • Renewable energy concept in each level planning	• Building height and density, insulation, ventilation, and energy	• Master and zoning plans at canton and municipal level • Mobility (parking spaces)	• Every building is registered in terms of heritage quality

Zero Emission Buildings, to develop emission-free buildings and neighborhoods. Switzerland derives its regulations from the SIA building codes and the MOPEC framework, which provide high-performance standards for energy efficiency. The current Swedish building regulations set requirements for the maximum amount of energy that can be used per floor area and year, expressed as primary energy, in line with the European goal to minimize the energy used within the building sector.

Other than codes and guidelines, various voluntary certifications for energy-efficient buildings and neighborhoods are followed across countries. For instance, LEED and BREEAM certifications are internationally recognized and applied in all the presented countries. In addition, Switzerland places significant emphasis on the Swiss Minergie® label for energy-efficient and eco-friendly buildings. Countries offer various tax incentives and subsidies to encourage solar energy adoption. In Canada, financial incentives, tax credits, and grants play a crucial role in promoting solar adoption. Italy offers tax deductions for building requalification and renovations, with deductions ranging from 50% to 90% based on the type of intervention. Switzerland offers federal subsidies that cover up to 30% of the investment, with an emphasis on the self-consumption of the electricity produced. In a similar way, the "plus customers" scheme in Norway exempts customers from paying network rent and fees from consumption that is covered by self-produced electricity or from feeding such electricity into the public grid. Moreover, a fixed economical support for the installation of photovoltaic systems in private households is guaranteed, in addition to a proportional support based on the capacity of the system. Sweden and Italy also provide subsidies and incentives to promote the widespread adoption of PV solar power.

Table 2 presents a summary of the main regulations and common practices developed to achieve high performance in the countries considered. It can be observed that there are few initiatives to protect solar access and installed solar technologies in these countries, however these initiatives are still relatively limited, and not well organized.

5.2 Recommendations on solar legislations

Despite significant progress that the studied countries have made in promoting solar energy, solar regulations and policies

TABLE 2 Regulations and common practices in solar and energy efficient neighborhoods.

Country	General solar regulations	High-energy performance codes	Voluntary certifications and common practices	Financial incentives and tax deductions
Canada	• Federal system promotes solar adoption and energy efficiency • No specific solar access laws; provinces have diverse regulations • Toronto's official plan prioritizes sunlight and sky views, and the Toronto Green Standard mandates solar-receptive building designs • Town of millet: right to light • Solar and Photovoltaics ready guidelines by NRC.	• National energy code • Pan-Canadian framework • BC energy step code • Ontario building code • Toronto's zero emissions building framework	• ASHRAE 189.1–2017 • ANSI/GBI 01–2019 • LEED • BREEAM • NZEB Certification • Passive House US	• Solar energy adoption is promoted *via* financial incentives, tax credits, and grants
Italy	• Urban planning prioritizes mitigation over adaptation • SEAP and SECAP are key legislative instruments • National laws regulate daylight levels; municipal standards ensure visual comfort and set residential-to-public space ratios • National-level regulation for new buildings require mandatory installation of PV and/or solar thermal technologies	• New or renovated buildings must meet European NZEB standards • The national standard includes various requirements for thermal performance, heat exchange, solar area, HVAC efficiency, hot water production, and transmittance limits	• EPCs (mandatory) • CasaClima • ITACA • ARCA • LEED • BREEAM • WELL • Passive house	• Tax deductions: 90% for energy-efficient requalification and renovation (incl. grid-connected PV systems), 50% for PV systems only • VAT reduced to 10% for purchasing and installing PV • Regional incentives
Norway	• No standard for solar neighborhoods planning • TEK17 includes recommendations for outdoor solar access, and indoor daylight and view • Neighbors Act and Planning and Building Act regulate the installation of solar systems in cities • SAK10 allows PV systems to be installed without formal public authority approval if certain requirements are met.	• TEK17 • NS 3700:2013 Criteria for passive houses and low energy buildings–Residential buildings • NS 3701:2012 Criteria for passive houses and low energy buildings–Commercial buildings • Passive house standard derived from the German Passive House Institute • Outcomes of FME ZEN and FME ZEB Research Centre	• SINTEF Building Research Design Guides • RIF Daylight in buildings • FutureBuilt • BREEAM-NOR • LEED • Nordic Swan Ecolabel • WELL	• Fixed economic incentive for solar system installation in private households, plus proportional incentive based on power capacity up to 20 kWp • Additional incentives by combining electricity generation with ST or storage • Plus-customers scheme exempts from paying network rent and fee for self-produced electricity
Sweden	• Detailed development plans: Geometrical plan details impact local solar energy conditions • Solar energy systems on existing buildings may not always require a permit, while new buildings always do	• Swedish building regulations align with European goals, specifying maximum energy use per floor area per year, measured as primary energy, to minimize energy consumption in the building sector	• CityLab • Miljöbyggnad • NollCO2 • LEED • BREEAM-SE	• Subsidies for 20% of the installation cost for grid-connected PV. • Subsidies for 50% of the installation cost for storage systems for local energy production
Switzerland	• Energy Strategy 2050 and Federal Act on Energy boost solar power on roofs and facades • The Swiss Federal Office of Energy (SFOE) issues solar PV consumer communities' guidelines • Specific regulations by canton based on SIA and MOPEC regulatory framework. Thermal and PV solar installations generally compulsory for new and renovated building	• Regulations stem from SIA (Swiss Society of Engineers and Architects) building codes for energy efficiency and a MOPEC framework negotiated among cantons • High-performance standard (HPE) and very high-performance standard (THPE) for new and retrofit buildings	• CECB • Minergie • SNBS-Buildings • SNBS-Neighborhood • Cité de l'énergie • LEED • BREEAM • DGNB • SEED-Next	• Federal subsidies cover around 30% of investments, and the model relies on self-consumption of produced electricity

are still rather scarce and sometimes ambiguous. To enhance solar energy capture and utilization and to address the identified gaps in existing regulations, countries should develop systematic multi-level approaches, involving local, state, and national levels of government. These approaches should be designed to ensure that regulations are tailored to meet the needs of regional and local communities, while adhering to common standards and best practices. Recommendations based on observations of current policies and of regulatory gaps in sensitive areas. are presented below.

5.2.1 Solar rights and access

Solar rights and access must be protected by establishing and enforcing of rigorous regulations, aiming at maximizing the potential of buildings and their surroundings to capture and utilize solar energy. This may require national legislative bodies to enact laws that limit shading on buildings and public areas, protect the right to install solar energy generation technologies, reduce restrictions and local zoning that inhibit these installations, and standardize the permitting process for these installations. Although some of these policies already exist, their effectiveness hinges on their incorporation into specific laws, directly influencing building and zoning codes. The distinction between solar access and rights, along with suggested actions are outlined below.

- Solar access can be upheld by:
  - o Solar access laws that aim to limit shading from surrounding and nearby structures, trees, or other obstructions. These laws can place restrictions on the maximum height of neighboring buildings and structures.
  - o Setback requirements that define minimum distances to be maintained between buildings and surrounding structures including trees, to prevent overshadowing.
  - o Zoning and land use codes that provide different provisions to preserve solar access and prevent potential obstruction of solar access by future developments.
  - o Solar easements, which are legally binding agreements to safeguard the solar access of property owners and to limit solar obstruction by adjacent properties.
- Solar rights are defined as legal protections that allow property owners to capture solar radiation on their property for energy generation (Bronin, 2009). These rights should:
  - o Ensure that the capacity to install solar panels and related equipment is not unreasonably restricted or interfered with.
  - o Protect existing solar technologies from undue shading and obstruction.
  - o Restrict the creation of easements, covenants, or other legal restrictions that could interfere with the capacity of a property owner to install solar energy systems.
  - o Protect from zoning restrictions that limit solar installations, provided they meet reasonable aesthetic and safety standards.

5.2.2 Spatial considerations

Spatial considerations are crucial for the effective deployment of solar strategies and can be incorporated within regulations as summarized below.

- Urban planning and zoning should prioritize solar exposure by optimizing building orientation and street layout to maximize active and passive solar energy use. Some Italian frameworks already incorporating orientation considerations for improved solar access.
- Land-use planning and zoning regulations should encourage mixed-use neighborhoods to enhance solar energy utilization through complementary demand profiles, as seen in the Canton master plan under Switzerland's Federal Act on Spatial Planning (art. 8). Streamlined permitting and incentives from municipalities can support such developments.
- Building density, spacing, and height significantly impact solar energy capture. These factors recognized in Italy, Sweden, and Switzerland should be collectively addressed in regulations to prevent shading issues and ensure aesthetic integration of solar energy solutions.

5.2.3 Technical regulations

- Technical regulations should be developed to govern solar energy generation, particularly grid connection and storage integration, ensuring flexibility for technological advancements while maintaining grid resilience and stability. Key aspects that such regulations should address include:
- Grid upgrading: regulations must be updated to support the electrical grid's modernization, enhancing its capacity for solar energy integration and addressing solar power's variability and intermittence.
- Interconnection standards: technical standards that oversee the connection of solar systems to the grid, should be established and implemented to ensure safety and reliability while reducing administrative barriers.
- Storage integration: regulations and standards can be developed to manage the integration of energy storage systems such as batteries with solar installations, to ensure efficient storage and utilization of excess solar energy.
- Solar-integrated microgrid regulations: establish clear regulations for microgrids to incorporate solar energy ensuring they meet specific performance criteria for reliable integration and align with local, regional, and national energy policies.

5.2.4 Economic and financial incentives

This work demonstrates that incentives significantly enhance the economic viability and adoption of solar technologies, which can be incorporated into various governmental regulations as follows:

- Financial incentives and subsidies: exploring financial incentives such as tax credits, rebates, innovative financing, and government grants is key, but to support the development of the solar industry. However, these incentives require ongoing evaluation and updates for continued effectiveness.
- Utility rate: the structure of utility rates can be revised to ensure an effective support to solar energy. Strategies that can be employed include the implementation of net metering, feed-in tariffs, and time-of-use pricing. Other strategies can take into account the time of generation to encourage energy production during peak demand periods.
- Energy storage incentives: besides subsidies and financial incentives for solar energy generation, it could be beneficial to develop financial incentives for solar energy storage.
- Community solar programs: develop guidelines for community solar programs to enable equitable solar energy access for residents unable to install solar panels on their properties, particularly focusing on accessibility for low-income communities. These programs can be integrated into the utility rate structure to offer financial benefits to subscribers.

5.3 Synergies between solar neighborhood planning and urban planning

The paper emphasizes the narrow integration of solar neighborhood planning within broader urban planning, highlighting the potential of urban design to optimize solar access through strategies like building density, spacing, and height to minimize shadowing (see 5.2.2). Other urban planning aspects, including heritage preservation, competing for surface availability with other technologies like green roofs, and fire safety standards for tall buildings, can affect solar energy strategies. Urban planning regulations should therefore systematically expand to include the installation of solar panels on alternative surfaces beyond building roofs and facades, encompassing car and bike shelters, noise barriers, and road coverings.

Urban planning intersects with other fields that can be more or less directly related to solar planning. This includes climate change adaptation through mitigating heat island effects with solar passive strategies and compensating for cooling demand with solar PV panels. Additionally, urban planning can facilitate the use of solar energy for e-mobility recharge and utilizing e-car batteries for storing solar energy, among other initiatives.

Several of the recommendations presented above will accelerate the decarbonization of national building stocks, with renewable on-site energy production being crucial for climate-friendly initiatives like Positive Energy Districts (PEDs) and Zero Emission Neighborhoods (Brozovsky et al., 2021). Facilitating on-site renewable solar energy production, implementing microgrids and simplifying the exchange and trading of self-produced electric or thermal energy can be important components for faster and wide-spread adoption of PEDs and similar concepts. Similarly, passive solar strategies at neighborhood and building scale can significantly reduce energy use for heating, cooling, and lighting.

As discussed, technical challenges may range from the detailed building technology to the neighborhood's electricity network and energy system. The integration of solar panels on building envelopes need to meet building codes (thermal aspects, water -and airtightness, fire-protection etc.) and not least the architectural quality of the building. Solar panels and roof/façade materials should be designed for aesthetic harmony. More flexibility is needed regarding size, colour, hues, patterns, to improve the design and use of sustainable materials. In parallel, urban regulations need to be adapted to enable the integration of solar strategies in protected heritage areas. Raising awareness among decision-makers about available strategies and their potential can expedite the deployment of solar solutions.

Another technical challenge is the grid connections and storage integration, to ensure grid resiliency and stability. As mentioned above (5.2.3), Legislation is needed around the grid infrastructure, integration of storage and microgrids.

6 Concluding remarks

This paper aims at reviewing regulations in traditional urban planning, as well as legislations and standards for high energy performance developments, across five countries. The paper identifies gaps in existing regulations, standards and codes, and highlights the need for future regulations to protect solar access and rights, as well as to support the deployment of solar technologies on large scale.

The five countries considered - Canada, Italy, Norway, Sweden and Switzerland - present many interesting approaches to traditional neighborhood planning. Although there are some references to climate-related regulations, such as the reduction of solar radiation in outdoor areas during summer, these regulations are not always specifically tailored to the general climate of the country, or to specific regional and local climates. Energy-related regulations consider climate with a slightly more structured approach, through efforts to reduce energy consumption for heating and cooling energy demand. Solar energy legislations are generally scare and not rigorously planned. On the passive solar energy side, they are mostly concerned in ensuring adequate levels of daylighting (in some countries). Other countries, e.g., Italy, have developed legislations encouraging the installation of solar systems (PV and ST) to achieve a certain level of electricity as well as to heat a specific percentage of domestic hot water. Although there are various other incentives for the installation of solar technologies, these incentives are relatively limited and solar technology continues to face a range of zoning constraints, impeding the widespread adoption of solar technologies.

Currently, there is no specific standard to address the planning of new/solar neighborhoods. The review of the work highlights some shortcoming, but also opportunities where existing regulations can be modified to incorporate solar access protection. For example, most countries have regulations regarding heights of buildings and setbacks. These can be modified to significantly reduce overshadowing of critical equatorial-facing facades and roofs, in both new and refurbished developments. Such regulations should be an integral part of enforceable laws that clearly delineate solar rights and access and outline the rights of property owners to capture and utilize solar energy. Conversely, there is a need to formulate legally binding legislations to safeguard the installation of solar technologies, in buildings and neighborhood areas. These regulations should address not only unreasonable installation restrictions, but also physical shading obstructions that can affect the performance of the solar technologies. In addition, the education of the public on solar rights and access is a key factor to promote awareness and compliance with these regulations. Other important policies that regulatory authorities should consider are related to technical and financial issues. On the technical side, it is important to establish clear legislation on grid upgrades to accommodate the increase in energy generation, associated with greater penetration of solar energy. Standards for the connection of solar systems, the integration of storage, and the design of solar integrated microgrids, should also be developed and regulated. At the financial level, innovative financial incentives should be developed and integrated into the regulatory system. These should be continuously evaluated and updated to reflect various changes including the technological progress and associated market value. Incentives can include tax credits, rebates, time-of-use and time-of-generation, as well as structured support for solar community programs.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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