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Review

Energy systems in sustainability-profiled districts in Sweden: A literature review and a socio-technical ecology approach for future research

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ABSTRACT

Over the past 30 years, several sustainability-profiled districts have been developed in Sweden with high ambitions for the energy systems, such as Hammarby Sjöstad in Stockholm and Western Harbor in Malmö. Research into energy systems in urban districts is interdisciplinary and therefore spread over different areas, which means that an overview of the current state of knowledge and lessons learned is lacking. This semi-systematic literature review aims to provide an overview of previous research on the planning, development, and evaluation of energy systems in sustainability-profiled districts in Sweden. The review of 70 journal and conference articles reveals seven research themes in the interdisciplinary nexus of energy systems and sustainability-profiled districts: (1) Conceptualizations and critique of sustainability-profiled districts, (2) Evaluations of energy goals and requirements, (3) Technical and economic assessments of heating and electricity systems, (4) Integration of innovative (energy) solutions in urban planning, (5) Stakeholder perspectives on energy systems, (6) Stakeholder collaboration on the building and the district level, (7) Governance and policy instruments for sustainable urban development and energy systems. We use a socio-technical ecology approach to critically discuss the existing research on energy systems planning, development, and evaluation to guide future research on energy systems development in urban districts. An increase in integrated approaches across all identified research themes and relationships between scales, phases, and impacts are discussed as central observations that can guide future research. Future research is needed on new or better-adapted energy indicators, the inclusion, perspectives, and roles of (new) stakeholders, and the consideration of ecology and nature in research on the planning, development, and evaluation of energy systems.

1. Introduction

Almost a third of the global final energy use and 28 % of energy-related carbon dioxide (CO₂) emissions are related to the building sector [1]. The European Green Deal states that by 2030 greenhouse gas emissions should be reduced by at least 50 %, and by 2050 there should be no net greenhouse gas emissions [2]. The development of sustainable and efficient energy systems for heating, cooling, and electricity supply and energy-efficient buildings is central to achieving these climate targets in the built environment. Since the 1990s, the National Government of Sweden has set energy use and carbon footprint objectives. To reach these objectives, local activities and efforts on climate impact reduction and urban development have been supported by the Swedish

Government [3]. These activities and efforts have led to the development of several sustainability-profiled urban districts in Sweden over the past decades. Sustainability-profiled districts are districts that are designated to serve as models for sustainable urban development and as testing grounds for innovation [4]. Other terms often used to describe these innovative urban development projects are flagship developments, demonstration projects, and showcase projects. District development projects with a focus on sustainability are commonly referred to as sustainable neighborhoods, eco-districts, or sustainable urban districts [5,6]. The term sustainability-profiled district has recently been used by several Swedish researchers [4,5,7,8] and leaves room for analysis and discussion about the interpretation of sustainability in the specific context and timeframe.

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Sweden's most well-known sustainability-profiled districts are Hammarby Sjöstad in Stockholm and Western Harbor in Malmö. In these districts, innovative technologies, models for integrated systems, policy instruments, and collaboration forms for the development of sustainable energy systems have been tested. The planning and development processes of these districts have received international attention from practitioners and researchers [9] and are seen as exemplary practical initiatives in sustainable urban planning [10]. In the context of the European Green Deal and other policies that are in place to incentivize the building sector to improve the energy efficiency of buildings, research on energy systems in Swedish sustainability-profiled districts can provide important lessons learned and insights. These lessons learned and insights could contribute to the future development of and research on low-carbon communities (LCC), zero-emission neighborhoods (ZEN), and positive energy districts (PED), both inside and outside of Sweden. Energy companies, municipalities, property developers, politicians, users, architects, building owners and managers, and other stakeholders can benefit from these insights when making long-term decisions that contribute to sustainable energy systems and districts.

In this article, we review the literature on the planning, development, and evaluation of energy systems in sustainability-profiled districts in Sweden, developed over the past 30 years. The practice of energy systems planning, development, and evaluation is interdisciplinary [11,12], meaning that research and lessons learned are currently spread over several areas with limited integration – including urban planning, political science, energy science and engineering, governance, geography, and design. Therefore, the purpose of this literature review is to integrate the current state of knowledge by identifying the main research themes in research on the planning, development, and evaluation of energy systems in sustainability-profiled districts in Sweden and to provide insights and lessons learned that could be applied in both future planning and future research of energy systems in urban districts. In the discussion, we critically discuss the findings of this literature review by building on Hägerstrands socio-technical ecology approach [13]. Recent studies have shown the potential value of interdisciplinary systems thinking approaches for energy systems research and sustainable energy systems development [14] and suggested merging socio-technical and social-ecological systems approaches as a way forward for sustainability transitions [14–18]. However, socio-technical ecology is a pre-existing theory proposed by Swedish geographer Torsten Hägerstrand which is developed as an interdisciplinary integrated approach to advance understanding of how humans, different technologies, technical systems, and nature could co-exist [13]. In the context of PEDs, Guarino et al. [131] have also identified the potential of socio-technical ecology to understand the implications and assessment of energy systems in urban districts. Socio-technical ecology emphasizes the importance of analyzing the use of resources, such as energy, and connecting the use to geographical places. A foundation in socio-technical ecology is the local time-space, also known as an arena [19]. An arena is “spatially delimited but at the same time represents a more abstract way of thinking” [[20], p. 25] and could provide an interesting alternative to boundaries, which are used in systems thinking approaches to define what components constitute a system [21]. Defining the boundaries of energy systems has proven challenging and energy research has begun to question notions of boundaries and limitations [22–24]. An arena perspective highlights physical proximity and situational combinations as the essential features [21] and begins with a place as a totality in seeking to understand what is occurring e.g., different activities or interests regarding a particular issue [20]. Arenas could be of any scale and are rural or urban concrete places [19,25,26]. The urban district, which is the focus of this literature review, could be defined as an example of an arena because urban districts are important territorial delimited areas in urban planning and development processes. The urban district could be seen as a meeting place for different disciplines and stakeholders, where different spheres of power and

interests come together. From an arena perspective, time and space are inseparable and a concretization of time could be the urban development process, including the phases. For the discussion of this literature review, socio-technical ecology provides an approach for critical analyses of existing research in the interdisciplinary nexus of energy systems and sustainability-profiled districts.

The structure of the article is as follows. Section 2 presents a background to the Swedish context concerning urban areas, urban energy systems, and urban planning. Section 3 describes the methodology used for this literature review and the limitations of the study. In Section 4, we present the results of the analysis and in Section 5 we use a socio-technical ecology approach to discuss the results and present guidance for future research. Finally, in Section 6, we present the conclusions of the literature review.

2. Background

By situating this review of research on the energy systems in sustainability-profiled districts in Sweden, it is first necessary to provide a background of Swedish urban areas, urban energy systems, and urban planning to better understand the context of the literature review and the applicability of the findings in other contexts.

2.1. Urban areas and urban energy systems in Sweden

Urbanization is a strong trend, both globally and nationally in Sweden where 88 % of the population lives in urban areas, which corresponds to 1.6 % of Sweden's entire land area [27]. Sweden has three major cities (Stockholm, Gothenburg, and Malmö), a few expanding regional centers, large rural areas, and smaller cities and towns. Almost half of all households in Sweden live in multi-family residential buildings [28], comparable to Austria, Finland, and France [29]. In multi-family residential buildings, rented dwellings are the most common type of tenure (58 %), while 42 % consist of owner-occupied dwellings [30]. Of all dwellings in Sweden, 62 % are owner occupied and 38 % are rental. In the Nordic context, the percentage of owner-occupied dwellings in Sweden is comparable to Finland, where Denmark has more rental dwellings and Norway has more owner-occupied dwellings [31]. In Sweden, the residential and service sector uses the most energy of all sectors which accounts for about 40 % of Sweden's total energy use [32,33]. Half of the energy used in the residential and service sector is used for space heating and domestic hot water [33]. Since space heating is highly dependent on the outdoor temperature, energy use in the sector has large seasonal variations and can vary between individual years. Sweden has a long tradition of using district heating to provide space and domestic hot water heating in cities and denser urban areas. In Europe, the average use of district heating in buildings is still low and Sweden is among the countries with the highest implementation rate of district heating, along with Iceland, Denmark, Finland, Estonia, Latvia, Lithuania, and Poland [34]. In Sweden, 90 % of the multi-family residential buildings, 17 % of the single-family residential buildings, and 78 % of the non-residential buildings are connected to district heating networks [35]. Electricity and biofuels are more common for heating single-family houses [33]. The use of fossil fuels is limited in both Swedish electricity and district heating supply. Electricity is primarily generated from hydropower and nuclear power, each accounting for about 40% of the annual supply and conversion. The remainder of the electricity comes from combined heat and power plants and an increasing share from wind energy. Despite the dependency on natural gas for heating in many European countries [34], the natural gas grid in Sweden is limited to the west coast, and the use of natural gas for electricity and district heating supply, heating, and cooking is small [33]. District heating, historically based on fossil fuels, has switched since the 1970s to mainly biofuels and combustible waste as supply, as well as some recovered industrial waste heat [36]. As only 1 % of fossil fuels remain in the fuel mix, the majority of greenhouse gas emissions

come from the combustion of waste [37]. In Sweden, the average specific CO₂ emissions per MJ of district heating supplied are among the lowest in Europe, comparable to Norway and Iceland [34]. According to Werner [38] the challenges for the future of district heating in Sweden are lower energy demand for buildings to meet lowered system temperatures in district heating networks, competition about energy supply sources, new heat sources, higher integration between electricity and heating systems into smart energy systems, variable power supply from wind and solar power, variation in prices and new business models [38]. Urban districts have the potential to address some of these challenges and are therefore crucial in the energy transition as they could harness the potential for renewable energy generation and storage in an efficient and flexible way [23].

2.2. The Swedish urban planning system

In Sweden, urban planning is regulated by the Planning and Building Act [39]. The Act consists of regional plans, comprehensive plans, area regulations, detailed development plans, and building permits [40]. Only the latter two are legally binding plans, the regional and comprehensive plans can be seen as indicative. Therefore, the national and regional planning levels in Sweden are relatively limited, which gives power and responsibilities on the local level to the municipalities [41]. From an international perspective, the Swedish planning system is highly decentralized, and municipalities decide how, when, and where development takes place within their municipal boundaries [42]. Since 1998, the National Government has been running several support programs for municipalities to develop sustainable urban districts with a focus on stimulating innovation at a local level [3]. Over the last three decades, many Swedish municipalities have initiated and developed sustainability-profiled districts. In sustainability-profiled districts, ambitions for sustainable development and innovation often exceed (national) regulations. The Planning and Building Act allows for adapting to local and place-specific conditions because the content of the plans and the methods used are quite flexible [40,41]. However, since 2015, a change in legislation implies that municipalities may not impose their own (sustainability) demands on the technical properties of buildings, also known as special demands (*särkrav* in Swedish). These special demands are considered demands that are more ambitious than the national building regulation. This change in legislation was made because demands should be predictable and uniform across the country to save construction costs and to facilitate the industrial production of buildings [43,44]. However, special demands are still used in land allocation agreements to enforce stricter sustainability requirements than the national building regulations when the municipality is the developer or the landowner. It is unclear if this is “due to misinterpretations of the law or deliberate transgressions” [45], p. 9]. Swedish municipalities have extensive land ownership [46], so land allocation agreements are often used, alongside other policy instruments, including dialogue processes, guidance for developers, and voluntary initiatives by developers such as working with environmental certification [43,47]. Swedish sustainability-profiled districts have been internationally acknowledged for their efforts to develop and promote sustainable urban development models and to implement solutions [9,48,49]. The implemented technical systems, such as combined waste and heat systems, but also the development processes, in which technical systems and the urban planning process are integrated and public and private actors collaborate, have gained international interest [49].

3. Methodology

This article presents a literature review of research on energy systems planning, development, and evaluation in sustainability-profiled districts in Sweden. According to Sovacool et al. [50], a literature review aims to map the current state of knowledge and specific research gaps. Semi-systematic reviews are useful for understanding complex

research areas and broad topics and have “the ability to map a field of research, synthesize the state of knowledge, and create an agenda for further research or the ability to provide a historical overview or timeline of a specific topic” [51], p. 335]. Because of the breadth of the research and the diversity of disciplines contributing to the topic covered in this literature review, a semi-systematic approach was considered appropriate. In this section, we discuss the search strategy and data collection, the analysis, and the limitations of the methodology.

3.1. Search strategy and data collection

Systematic searches, by article title, abstract, and keywords, were carried out in two of the largest citation databases, Scopus, and Web of Science (January 20, 2022). To capture the broad range of articles relevant to this literature review, one broader and one narrower search string were used in the database searches. These search strings were developed over several iterations and several combinations of search words were tested and evaluated to improve the searches to target relevant research articles. For the broader search string, five categories of search words were identified, specifying the location, energy terms, urban areas, sustainability terms, and urban development phases relevant to this literature review, see Table 1.

The narrower search string, presented in Table 2, was developed based on names of sustainability-profiled districts already known to the authors or found through Google searches, in combination with the search words from the Energy category from the broader search string. Both search strings were composed by adding the operator ‘AND’ between each of the categories and then separating the search words within each category with the operator ‘OR’, meaning that at least one keyword from each category must be present in the title, abstract or keywords of an article for it to appear in the search results.

The database searches covered English and Swedish written journal and conference articles published over the last 30 years (between 1992 and 2021). Selecting 1992, as the start of the study period, was based on the year of the Rio de Janeiro Earth Summit, where almost all countries in the world signed an agreement to prevent “[...] ‘dangerous’ human interference with the climate system” [52] and on the fact that in 1992 the planning of the first sustainability-profiled district in Sweden (Hammarby Sjöstad in Stockholm) started.

Based on the flow diagram provided by the Preferred Reporting Items from Systematic Reviews and Meta-Analyses (PRISMA) [53], an exclusion process of two steps was applied: 1) initial screening and 2) eligibility, see Fig. 1. The records of the 3337 articles obtained in the database searches were uploaded into Rayyan QCRI, a web app for literature reviews, for sorting. Through its user-friendly interface and supporting features, Rayyan facilitates screening of the uploaded article titles and abstracts to identify relevant articles to include in the literature review [54]. Furthermore, it allows two or more researchers to work on the same project independently and simultaneously, thus increasing consistency and reducing bias in the screening process. The

Table 1
Search words based on five categories used in the broader database searches.

Location	Energy	Area	Sustainability	Development phase
Sweden	energy	urban	sustainab*	plan*
Swedish	electric*	district	climate*	develop*
	power	neighborhood	*carbon*	design
	gas	municipal	eco*	construct*
	heat*	city	*energy*	buil*
	cool*	town	environment*	process
	renewable*	residential	efficien*	follow-up
	solar	multi-family	CO ₂ *	evaluat*
	exergy	housing	*emission*	assess*
		mixed-use		monitor*
		brownfield		operat*
		greenfield		

Table 2
Search words based on two categories used in the district search string.

District				Energy
Hammarby Sjöstad	Brunnshög	Kiruna city center	Råbergstorp	energy
Norra Djurgårdsstaden	Tomtebo strand	Sege park	Glasberga Sjöterrass	electric*
Royal Seaport	Näringen	Östra Sala backe	Haga Sundsvall	power
Västra hamnen	Storsjö strand	Ulleråker	Vårvik	*gas
Western Harbor	Tamarinden	Rosendal	Centrum-Torsvik	heat*
Bo01	Sigtuna Stadsängar	Lindholmen	Alby	cool*
Masthusen	Jakobsdalen	Norrliden	Vilans strandäng	renewable*
Hyllie	Sätra	Kronan		solar
Kvillebäcken	Oceanhamnen	Östra Stranden		exergy
Masthuggskajen	Södra Munksjön	Grundviken		
Vallastaden	Skeppsbron	Lagersdal		
Ebbepark	Södra Butängen	Fröslunda		

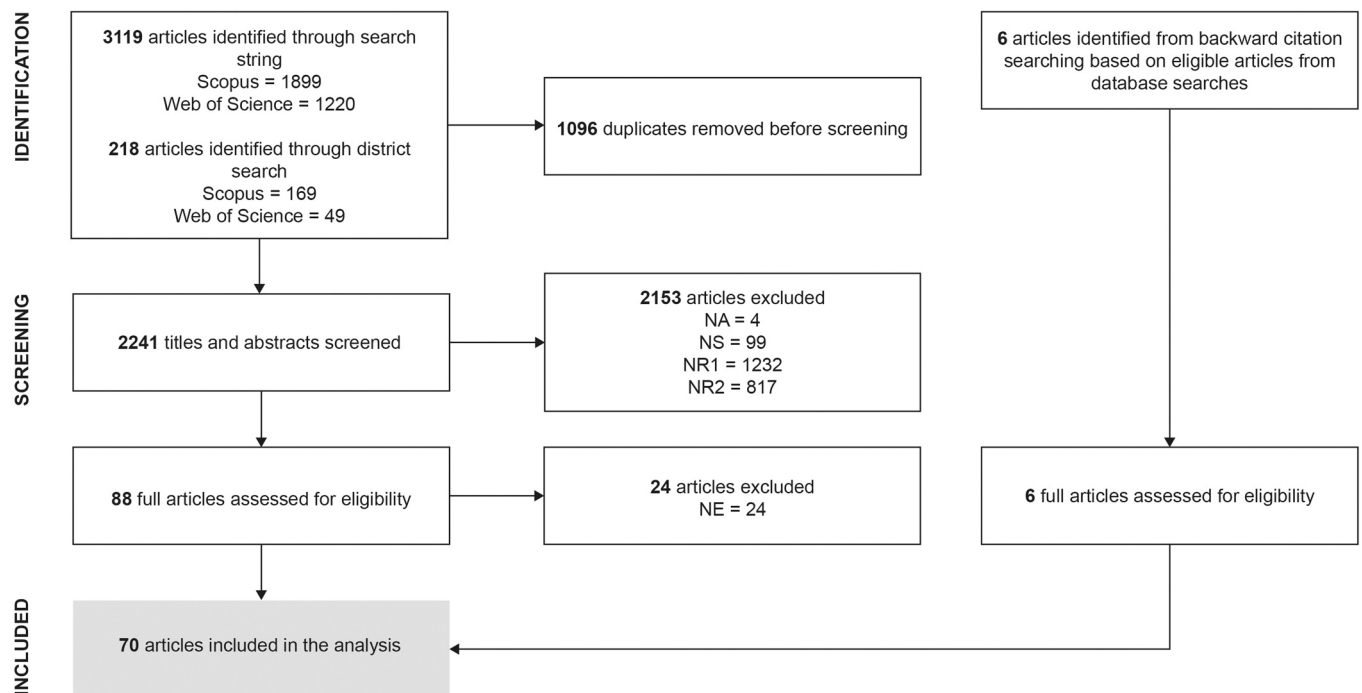


Fig. 1. PRISMA flowchart showing the method of data collection and sorting. See Table 3 for explanations of the exclusion codes.

use of multiple search strings and databases led to some overlap in the search results. The duplicates were removed using the deduplication feature in Rayyan in combination with some manual screening of the records. After the deduplication was completed, 2241 unique articles remained. To identify articles relevant for further analysis, five exclusion criteria were developed. These exclusion criteria, presented in Table 3, were used for screening the article titles and abstracts in Rayyan. In cases where the title and abstract did not provide enough context to decide about inclusion, the full-text version of the article was

Table 3
Exclusion criteria for the literature review (sorted in order of application).

Exclusion reasons	Code
Not a journal or conference article (i.e., book sections or presentations)	NA
Not related to any Swedish urban districts (non-Swedish context)	NS
Not related to energy in the built environment (i.e., tourism, transport, waste, industry)	NR1
Not related to new urban areas with a sustainability focus (i.e., existing buildings, larger scales, rural, individual buildings without relation to a specific urban area)	NR2
Lacking a clear energy focus (i.e., energy only mentioned once or twice in the article)	NE

reviewed outside of Rayyan. In total, 2153 articles were excluded from the screening, resulting in a final sample of 88 articles that were brought forward for eligibility assessment of the full text.

To supplement the database searches, backward citation searching was carried out by checking the reference lists of the 88 articles. From the backward citation search, six articles were added, resulting in a final sample for full-text analysis of 94 journal and conference articles. Because of the explorative purpose of this literature review, the full-text analysis was carried out in steps, applying an inductive approach. The first step was intended to provide an overview of the articles, by mapping information about the year of publication, research method(s) used, on which urban district the research was based, and which energy aspects and development phase(s) were investigated. Based on this information, another 24 articles were excluded, because the articles lacked a clear energy focus. This resulted in a final sample of 70 articles being included in the review, of which 56 were journal articles and 14 conference articles (see Appendix A for a complete overview of the included articles).

3.2. Analysis

Thematic analysis was used for the analysis of the articles included in

this review and the 70 articles were coded in NVivo software. As described by Braun & Clarke [55], p. 78, 79], “thematic analysis is a method for identifying, analyzing and reporting patterns (themes) within data” and is “essentially independent of theory and epistemology”. Because of the flexibility of this method, it is useful for analyzing and describing diverse and large data sets and for identifying key features. It was therefore considered a suitable method for analyzing the reviewed literature in this study.

The analysis was carried out in several steps. First, to create an overview of the content, we identified for all articles the purpose and research focus, the descriptions of the studied sustainability-profiled neighborhoods and their energy systems, and the sustainability goals mentioned. In the next step, using an inductive approach, several themes were developed based on the research focus of the articles. In the third step, the articles were sorted into these themes and analyzed further to understand the breadth of the research. Through this process, new themes were discovered, and the articles were reorganized accordingly. After several iterations, seven final themes were identified that provided a comprehensive overview of the articles and laid a foundation for further analysis of the articles. Some articles can be seen as part of multiple themes, but we have chosen to focus on the main topic per article and to assign each article to one theme. In Section 4.3, the themes are presented (see Appendix A for a complete overview of the included articles and the associated research theme).

3.3. Limitations of the methodology

This literature review has certain limitations. Although the use of a semi-systematic literature review approach enabled us to follow a rigorous search and review process, we only searched for journal and conference articles to keep the total number of articles manageable. We excluded gray literature, such as planning documents, energy plans, and evaluation reports that could provide valuable insight into energy systems planning, development, and evaluation. We recommend future research to include gray literature, monographs, and books. As mentioned in Section 3.1, we searched for journal and conference articles between 1992 and 2021, but the final sample of the literature review includes only articles published between 2003 and 2021 although the planning of Hammarby Sjöstad in Stockholm and Western Harbor started before. The lack of articles published before 2003 could be explained by the shift in publishing conventions, as it was previously more common to publish monographs and books rather than articles. Additionally, it is likely that more attention is paid to research on energy systems in urban districts after 2003 due to i.e., European Directives on Energy, research calls, and the importance of the local level for the implementation of the Sustainable Development Goals. Another issue was the variation in the quality of the included articles. We decided to include both journal and conference articles due to the interdisciplinary nature of the topic of this literature review and the practice in some disciplines of publishing primarily (or only) in conference articles. During the full-text analysis, we noticed that some conference articles lacked a clearly formulated goal and problem formulation, method description, or communicated results. Nevertheless, we decided to include conference articles from all disciplines because we aimed to provide an overview of the current state of knowledge and the research gaps of the interdisciplinary topic of energy systems planning, development, and evaluation.

4. Results

The results of the literature review are divided into three parts. In Section 4.1 an overview of the included articles is given. In Section 4.2 the sustainability-profiled districts that are included in the articles are described. In Section 4.3 an overview of the research themes that have been identified in the literature is provided.

4.1. Overview of included articles

The articles present research done on 13 sustainability-profiled districts in Sweden and some of the articles include multiple urban districts as case studies to make comparisons (see Fig. 2). The first three sustainability-profiled districts developed in Sweden (Hammarby Sjöstad in Stockholm, Western Harbor in Malmö, and Royal Seaport in Stockholm) have been explored to a greater extent than other newer urban districts, as also can be seen in Fig. 2.

4.2. The sustainability-profiled districts

The included articles focus on 13 different sustainability-profiled districts in Sweden. These districts have been developed in various urban areas in Sweden since 1992. Table 4 presents an overview of the 13 sustainability-profiled districts with their most important characteristics.

4.3. Identified research themes

In this section, the main research themes that have been identified in the analysis are presented. An overview of the seven research themes, a brief description of each theme, the timeframe of publication, and the number of articles included in the theme can be found in Table 5.

In the following sections, for each research theme, we discuss the common findings, lessons learned, and future research questions related to the planning, development, and evaluation of energy systems in sustainability-profiled districts.

4.3.1. Conceptualizations and critique of sustainability-profiled districts

The planning, development, and evaluation of energy systems in sustainability-profiled districts are influenced by how sustainability-profiled districts are conceptualized. Over the years, various concepts for sustainability on the district scale have emerged. In a 10-year study of Stockholm Royal Seaport, sustainability is understood from a performative perspective, meaning it is a concept that is local, temporal, and political [56]. The local understanding of sustainability means that the conceptualization of sustainability is situated in the specific local context of the project, the temporal understanding implies that sustainability is understood differently over time and the political understanding is related to the expression of values and perspectives, which depend on the political context [56]. The approach of Hallin et al. [56] contributes to a comprehensive and transformative understanding of the different conceptualizations of the included articles in this theme, focusing on the temporal, local, and political context of energy systems and urban districts.

Although urban development processes for urban districts are long processes and cities are constantly evolving meaning that conceptualizations also evolve during the development of one district [56], the articles in this theme show an evolution of the conceptualization of sustainability and energy over time, moving towards more integrated and complex concepts. In the development of Sweden's first sustainability-profiled districts (Hammarby Sjöstad in Stockholm and Western Harbor in Malmö), the emphasis was on environmental sustainability [57]. These districts are often referred to as eco-districts. Eco-districts are conceived as districts in which climate mitigation and adaptation are addressed with sustainable planning strategies, including state-of-the-art technologies, ecologically sustainable building methods, and renewable energy integration [58]. However, according to Hallin et al. [56], the focus in these eco-districts was often mainly on green technologies related to renewable energy. This is in line with the article by Koutra et al. [59] introducing the concept of zero-energy districts as an extension of the concept of eco-districts. Next to the conceptualization of Hammarby Sjöstad (Stockholm) as an eco-district, the Hammarby eco-cycle model as a concept received international attention, focusing on integrated environmental solutions on the district scale [60]. After

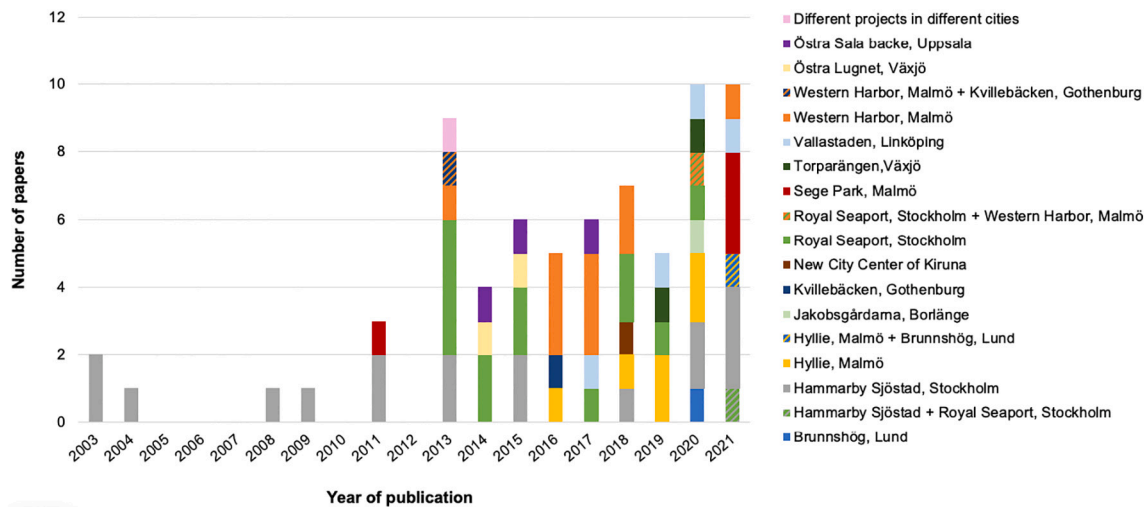


Fig. 2. Number of reviewed articles published between 1992 and 2021 and the sustainability-profiled districts studied in these articles (note that none of the articles included in the review was published in 1992–2002).

the application of the Hammarby model in Hammarby Sjöstad, the model was further developed in Stockholm Royal Seaport (Stockholm) and was called eco-cycle model 2 or Hammarby 2.0, and included regeneration, adaptation, and circularity as strategies [61]. The articles about eco-districts and the Hammarby model bring forward the lack of data as a common barrier to the implementation and monitoring of sustainable energy solutions on the district scale [61–63]. The need for data for the implementation and monitoring of for example energy solutions resulted in the development of the smart urban metabolism concept. The concept of smart urban metabolism uses ideas from the smart city conceptualizations to address limitations of the urban metabolism concept and is based on an ICT-enabled evolution of urban metabolism by the integration of high-quality and real-time data on a high spatial resolution with continuous feedback to all stakeholders [62–64]. Sensors are used to measure several aspects of energy flows on different scales and provide tailored feedback to specific stakeholders, for example to municipalities to follow up on environmental goals, to building owners to optimize energy use, and to users to understand the impact of energy use [64]. The importance of ICT and data-driven technologies is also acknowledged by researchers working with the eco-city concept, resulting in the conceptualization of the smart eco-city [10,65]. In a smart eco-city, the integration and synthesis of urban data improve environmental sustainability by for example the use of smart data-driven technologies to reduce energy use [65]. Parks & Rohrer [66] describe a shift in conceptualization from sustainable to smart and show that in the context of Malmö and the urban district of Hyllie the actors involved in sustainable urban planning see the potential for smart urban energy infrastructure. They show that it is not justified “to criticize smart city discourses as meaningless brands or empty signifiers” [66], p. 58].

The articles by Jönsson & Holgersen [67] and Kopljar [68] investigate the local understanding and translation of sustainability in the districts of Western Harbor (Malmö) and Brunnsög (Lund). Both articles highlight the importance of the connection of the local scale with wider scales because a narrow focus on the local scale brings the risk of limited discussions about sustainable urban development and the outcome of the urban development projects. The scale-related implications of sustainability and other ambitions at the local level should be considered in future planning.

In the past five years, articles have been published critiquing the conceptualizations of sustainability-profiled districts from social values and social perspectives. In an article about Hammarby Sjöstad (Stockholm), Medved et al. [60] introduce the concepts of eco-elitism and eco-gentrification, “meaning that just the most affluent, educated and

sustainability-conscious citizens of the upper-middle creative class populate new sustainable districts” [60], p. 35]. Other authors also point to socio-economic segregation and unaffordable housing in different sustainability-profiled districts in Sweden [10]. In the context of smart conceptualizations, issues of digital segregation and encroachments on individual freedom and privacy have been raised [62,64]. Holgersen & Hult [57] connect the way we understand space and measure emissions to the conceptualization of a sustainable urban district. In the Swedish context, the production perspective on emissions is dominant, but the consumption perspective reveals that how residents live in sustainability-profiled districts entails high emissions. In summary, it seems that the focus is shifting from more technical conceptualizations of sustainability towards integrated conceptualizations, including lifestyles, affordability, and inclusion. The article by Hallin et al. [56] shows a similar shift. They describe that the concept of sustainability has recently included “sustainable living and healthy lifestyle” [56], p. 1953]. To make informed decisions about how to achieve sustainable energy goals in urban districts and to understand the roles and power of actors and inequality in the processes, further empirical research is needed into how sustainability and smart conceptualizations have been understood in different local contexts [56,65,66].

4.3.2. Evaluation of energy goals and requirements

The articles included in the Evaluation of energy goals and requirements theme cover evaluations of the goals for the energy systems in the sustainability-profiled districts. As part of the planning processes of the sustainability-profiled districts, a sustainability program is typically developed based on the municipality's vision for the urban district [69–71], including goals for the energy system. The energy goals for the first sustainability-profiled districts (e.g., Hammarby Sjöstad and Western Harbor) were mainly focused on technical aspects, such as energy performance, specific technologies, and energy sources. In more recent sustainability-profiled districts, the energy goals also include the involvement of end-users, integrated systems, monitoring, and local energy supply (e.g., in Royal Seaport and Hyllie).

Energy performance goals for the buildings have been part of most of the sustainability-profiled districts. Since 2006, the Swedish building code includes energy regulations for new buildings with functional requirements for specific energy use or primary energy numbers in kWh/m² per year [69], based on used energy per heated floor area [71]. The energy performance goals for the buildings in the sustainability-profiled districts often go beyond the Swedish building code, e.g., 40 % lower than the Swedish building code [70] or the use of passive house designs [72]. It is common to include these stricter energy performance

Table 4
Overview of the sustainability-profiled districts and their most important characteristics.

Sustainability-profiled district	Urban area	Timeframe	Program	Energy system
Hammarby Sjöstad	Stockholm	1992 - ongoing	Mixed use, 12,700 dwellings	District heating, solar energy, biogas for cooking (limited)
Western Harbor (including Bo01)	Malmö	1998 - ongoing	Mixed-use, 10,000 dwellings	District heating, heat pumps, solar energy, small wind turbines
Kvillebäcken	Gothenburg	2004–2019	Mixed-use, 2000 dwellings	District heating
Hyllie	Malmö	2007 - ongoing	Mixed-use, 9000 dwellings	District heating, heat pumps, solar energy, wind energy
Östra Lugnet	Växjö	2007 - ongoing	Mainly residential, 750 dwellings	District heating, solar energy
Royal Seaport	Stockholm	2008 - ongoing	Mixed-use, 12,000 dwellings	District heating, heat pumps, solar energy
Brunnshög	Lund	2009 - ongoing	Mixed-use, 6000 dwellings	Low temperature district heating, solar energy
Vallastaden	Linköping	2011 - ongoing	Mixed-use (mainly residential), 1800 dwellings	District heating, solar energy
New city center	Kiruna	2012 - ongoing	Mixed-use, 3000 dwellings	District heating
Östra Sala backe	Uppsala	2014 - ongoing	Mixed-use, 2500 dwellings	District heating, solar energy
Sege Park	Malmö	2015 - ongoing	Mixed use, 1000 dwellings	District heating, solar energy
Torparängen	Växjö	2017 - ongoing	Residential, 300 dwellings	District heating
Jakobsgårdarna	Borlänge	2017 - ongoing	Mainly residential, 1200 dwellings	District heating, solar energy

requirements in the land allocation agreements between the municipality and the developers [69,72,73]. However, different studies show these stricter energy performance goals have not always been achieved in the sustainability-profiled districts [69–73]. Reasons for not reaching the energy performance goals are inaccurate energy calculations and simulations in the design phase, lack of heat conservation measures implemented, use of assumptions to report specific energy use, lack of monitoring and enforcement of energy performance requirements and the energy efficiency behavior of the residents [69–73]. To address the non-compliance with the energy performance goals, three main areas for improvement have been identified. First, the differences between predicted and actual energy use call for improvements in the energy performance calculation methods and simulation tools [69,70,73]. Second, the consequences of not reaching energy performance requirements seem to be unclear, which asks for a better definition of responsibilities, more follow-up, and clearer compliance [69,73]. Third, static energy performance indicators might be inadequate and other indicators might be needed to holistically evaluate the energy performance of buildings

Table 5
Overview of the seven research themes identified in the included articles.

Research theme	Theme description	Timeframe	Number of articles
1. Conceptualizations and critique of sustainability-profiled districts (Section 4.3.1)	This theme is about trends in the conceptualization of sustainability and energy on the district scale. The theme includes research on eco-districts, zero-energy districts, the Hammarby eco-cycle model, (smart) urban metabolism. Research seems to be increasingly critical about the conceptualization of sustainability from social values and perspectives.	2013–2021	14
2. Evaluations of energy goals and requirements (Section 4.3.2)	This theme is about the evaluation of energy goals and requirements for buildings and for energy systems or sources. The energy goals and requirements include more integrated aspects and need other ways of evaluating.	2013–2020	10
3. Technical and economic assessments of heating and electricity systems (Section 4.3.3)	The articles included in this research theme are technical and economic assessments of heating and electricity systems. Several indicators have been used to explore scenarios of heating and electricity systems.	2004–2021	13
4. Integration of innovative (energy) solutions in urban planning (Section 4.3.4)	This theme includes research on the socio-technical understanding of innovative (energy) solutions in urban planning processes and investigates e.g., solar energy and district cooling. Systems integration and the interest and knowledge of actors have been found as promoting factors for the successful integration of innovative solutions in urban planning.	2011–2021	5
5. Stakeholder perspectives on energy systems (Section 4.3.5)	The articles included in this theme investigate the perspectives of building sector professionals and users on energy systems in urban districts. A need for research on new ways of collaboration between professionals and users have been found in which the inclusion of all perspectives should be considered.	2016–2021	7
6. Stakeholder collaboration on the	This research theme concerns stakeholder	2008–2021	6

(continued on next page)

Table 5 (continued)

Research theme	Theme description	Timeframe	Number of articles
building and the district level (Section 4.3.6)	collaboration dynamics and shows the importance of trust, leadership, and the inclusion of broader stakeholder groups in the development of energy systems. Special attention is needed for the process of learning from stakeholder collaboration.		
7. Governance and policy instruments for sustainable urban development and energy systems (Section 4.3.7)	The articles included in this theme are about governance modes and policy instruments to realize energy ambitions in the urban districts on different levels. Most research views policy as top down by the municipality but there is an increased interest in involvement of users in the planning processes.	2003–2020	15

[69,71,73]. According to Holmstedt et al. [71], the building's energy use depends on many factors in addition to floor area, and current static indicators do not distinguish between building energy use and user behavior. Using dynamic and high-resolution data for the evaluation of energy performance has great potential and could increase the level of detail in the evaluation of energy use in buildings and households [71] and could contribute to realistic input data in energy calculation and simulation methods [69,73]. Next to the value for the evaluation of energy performance, dynamic and high-resolution data also provides a possibility to involve residents who are usually not part of building performance evaluation. Nilsson et al. [74] show the potential of home energy management systems which may lead to increased awareness of energy use, as well as increased home comfort for building users. The study by Glad & Gramfält [72] provides insight into how the involvement of building users in the evaluation of the energy performance of buildings can contribute to new insights on e.g., energy-related behavior and thermal comfort. In further research on the energy performance evaluation of buildings an interdisciplinary approach, combining analysis of quantitative energy measurements with findings from qualitative interviews, seems promising [74]. However, issues with personal integrity, technical installations for data collection, and data accessibility should be taken seriously and might obstruct research that includes comprehensive data on the household level [71].

In addition to energy performance goals for the buildings, requirements for the type of energy system or energy source have been implemented in several sustainability-profiled districts. In many sustainability-profiled districts, the municipality has included the requirement to connect the buildings to the district heating system in the sustainability program, e.g., in Linköping [72] and in Växjö [69,73]. Mahapatra et al. [69,73] evaluated the requirement of the municipality of Växjö to connect all new buildings to the existing district heating network, in terms of primary energy use and CO₂ emissions and compared it with the hypothetical scenarios of installing air-source or bed-rock heat pumps instead. They conclude that the requirement to connect to the district heating network in Östra Lugnet (Växjö) contributes to lower carbon emissions [69,73]. In other sustainability-profiled districts, the focus has been on local energy systems. As Austin [70] points out, one of the energy goals for Bo01, part of Western

Harbor (Malmö), was renewable energy generation, aiming for 100 % locally generated renewable energy. This goal was achieved through the implementation of photovoltaics (PVs) and a wind turbine for electricity generation, as well as solar collectors and geothermal heat pumps supporting the district heating and cooling systems. Pandis Iveroth et al. [75] conclude that Hammarby Sjöstad (Stockholm) is far from self-sufficient in terms of secondary energy because it heavily relies on the combustion of both local and imported waste. Including more local renewable energy generation and a significant reduction in building energy use would increase the degree of self-sufficiency and decrease CO₂ emissions. Not only quantitative studies should be carried out in further research, but also exergy, a measure of energy quality, analysis is of interest to evaluate energy flows in urban districts [75]. Kılıkş [76–78] investigates exergy on the district scale and analyzes the near net-zero exergy goal in Östra Sala backe (Uppsala), which means that the district generates as much energy at the same grade and quality as used on an annual basis [77]. The net-zero exergy goal requires a more integrated approach to optimize the energy systems for the district, including exergy measures for both supply and demand to use the energy quality efficiently. The three articles [76–78] present a promising approach to develop and evaluate the net-zero exergy goal at the district scale and propose new indicators, including exergy per capita.

4.3.3. Technical and economic assessments of heating and electricity systems

Sustainability-profiled districts often serve as testing grounds to explore new and innovative energy solutions. Technical and economic assessments are used to increase knowledge about different energy supply options or energy use scenarios and optimize energy-related investments and serve as a basis for decision-making. The articles included in this theme assess a broad range of parameters and technologies related to heating systems and the power grid. These studies use simulation models to evaluate scenarios based on technical and economic indicators, such as final and primary energy use, energy efficiency, economic costs, and CO₂ emissions.

As described in Section 2.1, district heating has a strong tradition in Sweden and represents the heating system baseline scenario in the heating system assessments reviewed in this theme. The articles cover studies of both energy demand scenarios and energy supply scenarios. The demand-side studies are performed during the early phases of the district development processes to explore the parameters that affect the total load curve and the variations. These studies show how site-specific conditions, the energy performance of the buildings, the use of the buildings, the district heating temperature, and heat losses in the district heating network strongly influence technical and economic indicators [79–81]. The energy supply scenario assessments provide insights into how traditional district heating systems can be transformed towards the fourth and fifth generation of district heating by including distributed heat pumps, prosumers in district heating networks, and different supply technologies for district heating [82–84]. The studies highlight the potential of heat pump technologies including cooling [82] and lower district heating temperatures through e.g., the recovery of excess heat which is largely available [80,83,84]. The economic assessments demonstrate that distributed heat pumps have a higher levelized cost of heating than district heating alternatives, mainly because of the investment costs [82,83], while heating systems with waste heat recovery can lower the levelized cost of heating [83]. Large-scale heat pumps also prove to be more cost-efficient due to economies of scale [82]. However, these studies are highly context-dependent, as they are based on price assumptions for district heating, economic incentives for waste combustion in district heating [82], and the existing energy systems in the local context [84]. Future research on the assessment of demand and supply scenarios for heating should include user comfort conditions [82], prosumer behavior [84], real measurement data for occupancy [79] and more comprehensive economic assessments to develop economically viable business models [84].

The purpose of the articles studying scenarios for the power grid is to understand the balance between the supply and demand of electricity and to assess several ways of managing the load to match electricity availability, either by storage [85,86], by demand response [87–90] or by a combination of the two [91]. These studies of the power grids show a shift towards more comprehensive assessments, driven by increased electrification, intermittent power generation, and the integration of smart technologies. The power grid assessment studies demonstrate that CO₂ emissions can be further reduced by the optimization of load shifting through including heating, and hot water [89], by developing integrated energy systems with (distributed) batteries [85,91], and by peak shaving through proactive energy behavior showing price and CO₂ signals to consumers [87,89,90]. The economic assessment of a battery storage system shows limited profitability in use, but costs are expected to decrease as a result of further development of storage technologies [91].

Further optimization of demand-side management strategies and more integrated heating and power systems have the potential to reduce primary energy use and CO₂ emissions and are expected to become increasingly financially competitive [81,83]. However, such systems and strategies require significantly more interaction and collaboration between actors, e.g., professionals from the electricity, heating, and transport sector, urban planners, citizens [85], as well as building owners [84], compared to more traditional systems. Thus, the complexity of the implementation is seen as a major barrier in the transition to smarter and more integrated systems.

4.3.4. Integration of innovative (energy) technologies in urban planning processes

To integrate new and innovative (energy) technologies in sustainability-profiled districts, urban planning processes, and practices need to adapt. The articles in this theme consider solar energy, ICT solutions, district cooling, and thermal collectors as innovative energy technologies and provide a socio-technical system understanding of how these technologies are integrated into the urban planning processes for urban districts.

Three articles explore the integration of solar energy in urban planning processes and practices behind successful examples of the implementation of solar energy systems [47,92,93]. Published in 2003, 2011, and 2021, these articles provide an understanding of solar energy integration over time. The main lesson learned from these articles is to start solar energy mapping or simulations as early as possible in the planning process to facilitate the implementation of optimal solar strategies in the district. Barriers that prevent the successful implementation of solar energy in the districts include the absence of legal instruments supporting solar energy systems integration [47], and the lack of awareness and knowledge of both public and private actors on the optimal utilization of solar energy on the district scale which has been found in all three articles [47,92,93]. There is a need for simple indicators that allow for evaluation and can facilitate the transfer between initial solar potential studies and the installation of the system [47,92].

Similar findings have been presented in studies on the integration of other innovative energy technologies in urban planning. An article by Kramers et al. [94] explores how and when ICT or ICT-enabled solutions, such as smart grids and smart meters, could be integrated into urban planning processes and how ICT could contribute to reaching more sustainable energy systems. Pandis Iveroth et al. [95] examine why district cooling was implemented and thermal collectors were not implemented in Hammarby Sjöstad. Both articles found that the introduction of innovative technologies needs further systems integration, e.g., with the district heating system which demands other competencies, knowledge, and forms of organization with more actors involved [94,95]. Pandis Iveroth et al. [95] state that for successful integration of new technologies, the (political) interest of actors in the innovative technology, the fit with existing user practices, and the contribution to optimizing an existing (energy) system are important. The article

concludes that systems integration may have both a positive and negative impact on further innovation, as it enables the integration of new technologies that add value to the dominant system infrastructure but may also cause lock-in effects that prevent the introduction of innovative technologies. More research is needed to provide insight into the implications of system integration, innovation processes, and the degrees of integration [95].

4.3.5. Stakeholder perspectives on energy systems

The planning, development, and evaluation of sustainability-profiled districts and energy systems involve many stakeholders. Stakeholders can be actors involved in the planning process but also actors involved in the use of the district. According to Olson et al. [96], previously the focus was mainly on what needs to change, but who has the agency to catalyze and realize change is increasingly on the (research) agenda. The research examining stakeholder perspectives on energy systems shows that there are two groups of stakeholders whose perspectives have been examined. The first group consists of the building sector professionals, and the second group are the users of the district and the buildings, such as residents and people working.

Four articles investigated the perspectives of building sector professionals and include the perspectives of developers, property owners, urban design professionals (architects, landscape architects, urban planners, and urban designers), municipalities, and energy companies. According to Wallhagen et al. [97], urban design professionals can primarily influence the environmental performance of the built environment as key stakeholders in the early design phases. From the analysis of the perspectives of the developers [98,99], property owners, the municipality, and the energy company [100], the importance of a holistic understanding of sustainability in urban development and energy planning is highlighted. The focus has been mainly on economic and technological values, but social values, including trust, engagement, ownership, democratization, and independency should also be included in the development of sustainable energy systems [99,100].

Investigating user perspectives related to the planning, development, and evaluation of energy systems appears to be a recent research topic. The articles focusing on user perspectives highlight the key role of users or consumer citizens in sustainable energy systems in urban districts and aim to understand user perspectives on different options for decentralized energy systems [101], on thermal comfort in passive houses [102], and on actions that citizens and building owners can carry out to reduce consumption-based emissions [96]. The articles in this research theme propose promising methods to further understand the roles, agency, and perspectives of users, such as personal diary studies [102], a combination of a back-casting study and stakeholder analysis [96], and stakeholder consultation workshops [101].

Several articles emphasize the need for collaboration between building professionals and users [98–101]. Hagbert & Femenias [98] state that an increased collaboration could foster more innovative solutions, but that the forms of collaboration or involvement still need to be defined. The emergence of new (non-commercial) stakeholder groups, such as citizen energy communities and decentralized owners [99,100] could be seen as promising models. Bögel et al. [101] propose energy start-ups, particularly digital platforms, and marketplaces as arenas for collaboration between energy producers and consumers. Business models, policies, regulations, and financial support systems still need to be developed to enable these types of solutions [101], preferably in a way that the profit can remain within the community [99]. This asks for more research considering the interests and perspectives of all stakeholders involved. The analytical framework developed by Palm [100] could be amended and advanced in future research to understand how energy solutions have been discussed in different arenas by stakeholders.

4.3.6. Stakeholder collaboration on the building and the district level

Sustainability goals are only achieved through collaborative efforts

between stakeholders [103,104]. Research on stakeholder collaboration focuses on the building level or the district level. On the district level, the focus is on collaboration processes within the project team of the municipality for environmental management in the district [103,104] and between broader networks of private companies, authorities, and housing cooperatives [105]. On the building level research investigates the collaboration between the municipality, property developers, and architects to reduce building energy use [106,107] and between different building sector professionals and energy models as (non-human) actors [108]. Using Actor-Network Theory, Eidenskog [108] shows that including technical devices on “equal terms as other actors” in the analysis helps to better understand the relationships between them [108], p. 229).

All stakeholder collaboration research identified and analyzed tensions and goal conflicts. The goal conflicts that have been examined in stakeholder collaboration are between design and energy efficiency [104,108], between economic and environmental objectives [103], between inconsistent objectives from different planning documents [104], between professional cultures [106] and between innovation and established practices, mindsets, norms, political agendas, and infrastructure [105]. Two lessons learned are found regarding stakeholder collaboration. The first lesson learned is that trust between stakeholders is essential for collaborative processes [106,108]. To build trust, the importance of leadership to develop networks and create well-functioning relationships has been mentioned in several articles [105,106]. However, the vulnerability of the dependence on personal relationships and on individuals for building trust was highlighted as a challenge [105]. The second lesson learned is that the inclusion of broader stakeholder groups in the collaboration contributes to developing a more sustainable energy system [103–105,107]. Early and broader inclusion of stakeholders could create a sense of joint ownership and could result in realizing more aims in the district, in a way that strengthens the development of professional networks, as well as mutual learning [104–106]. Three articles highlight that learning from the stakeholder collaboration process often only takes place for the stakeholders involved and that it seems difficult to disseminate beyond the project [104–106].

4.3.7. Governance and policy instruments for sustainable urban development and energy systems

As explained in Section 2.2 of this article, urban planning in Sweden is highly decentralized and the municipality plays an important role in initiating, encouraging, and managing sustainable urban development [41]. Municipalities are often dependent on private developers to implement sustainability goals and use governance and policy instruments to support, steer, or direct the planning, development, and evaluation of energy systems in urban districts [41,109]. Within the research theme Governance and policy instruments for sustainable urban development and energy systems, research has been done on both national and local level policy instruments concerning sustainable urban development and energy, on governance experiments, and on different modes of governance and combinations of policy instruments.

On the national level, there is a strong focus on the national support programs of Sweden for local developments. Between 1998 and 2012, the National Government of Sweden provided several economic incentives to support sustainable urban development at the local level. The Local Investment Program (1998–2002) was the first economic subsidy program. This program was meant for Swedish municipalities to work with local companies and organizations to reduce environmental impacts through the implementation of energy and resource-efficient technologies [110,111]. However, only half of all the programs that received funding from the Local Investment Program were delivered as intended [110]. Other national subsidy programs were the Swedish Delegation for Sustainable Cities (2008) and the Climate Investment Program (2012). These programs made it possible to test (energy) innovations and develop integrated solutions [112]. Next to these

financial support programs, the Swedish Government launched the Building-Living Dialogue project which consisted of several programs for urban governance for sustainability [46]. One of these programs was the Constructive Dialogue (2004–2009) carried out in six Swedish municipalities and aimed at a more sustainable built environment by 2025 by developing methods for constructive dialogues in urban development processes. Smedby and Neij [113] analyzed the Constructive Dialogue program and indicated “a difficulty in simultaneously considering process and environmental concerns and a tension between consensus and cutting-edge solutions” [113], p. 148).

Since 2016, research has focused on governance experiments for sustainable energy systems and looked at new ways of governing to implement energy goals. These governance experiments include ambition levels in land allocation agreements [114], quality criteria-based land allocation competitions [109], and voluntary policies with dedicated actions for developers, municipal departments, and other stakeholders [115]. These other ways of governing correspond to a change in the law that limits the possibilities of Swedish municipalities to impose stricter (sustainability) demands on buildings, as described in Section 2.2, and can be viewed as more voluntary and less top-down than before 2016.

While most articles in this research theme investigated one specific policy instrument, several articles focus on a comprehensive understanding of the different modes of governance and combinations of policy instruments to reach energy goals. A wide variety of policy instruments have been discussed in these articles, including sustainability programs for the urban district [8,111,116–118], land allocation agreements [8,111], the Local Investment Program [111], a quality program for the buildings [46], detailed development plans [116], developer dialogues [8,116], the Building and Living Dialogue with the private sector [46], information campaigns, seminars/workshops for developers and architects [8,116], a climate contract between the energy company and the municipality [41,118,119], municipal level agendas for sustainability [41,46,118] and national level regulations [119]. The literature mainly views policy as top-down by the municipality and emphasizes a promotive and proactive role of municipalities in Swedish sustainable urban district and energy system development [41,46,113,116,120]. A common critique is the lack of involvement of users and residents in the planning processes. Several articles [111,117,120] highlight the importance of the role of users and residents in sustainable energy systems. Next to the involvement of users and residents, the (horizontal) collaboration with other actors, political will [46,116], and governance support from the regional and national level have been emphasized for the successful implementation of energy ambitions [41,117]. A risk that has been identified in the articles about a combination of policy instruments, is the lack of alignment of the different policy instruments, from different policy levels for example, resulting in conflicting goals or unclarity for the actors involved in the development processes [111,117,119].

Further research is needed into urban social sustainability and local communities in development processes for sustainability-profiled districts [120], comparative studies of local governance conditions [41,113,114] and multi-scale and systemic policy-mix analysis to understand how trade-offs and tensions occur over time [111]. These types of research could contribute to a further understanding of the limitations and opportunities of the application of the different modes of governing for more sustainable energy systems in urban districts.

5. Discussion

The seven research themes identified in the literature review confirm the interdisciplinary character of the topic of energy systems planning, development, and evaluation and provide insights and lessons learned that could be applied in both future planning and future research of energy systems in urban districts. Using a socio-technical ecology approach [13], several observations can be made about the literature

reviewed in this article. Socio-technical ecology considers humans, technologies, technical systems, and nature in a specific place and also brings forward how people, artifacts, technologies, and nature in a specific location can sustainably merge and evolve [121]. In socio-technical ecology, local prerequisites are understood as the foundation of all urban developments which requires a comprehensive analysis of how people act, which technologies are chosen, and how technical systems are designed, built, and used in relation to the specific site. Socio-technical ecology as an approach has been applied in studies of innovations in energy systems [122], preservation of historical landscapes [123,124], and resource use in residential buildings [125]. Below we discuss an increase in integrated approaches and the advantages and opportunities this can bring, and the relations between scales, phases, and impacts as central observations of this literature review.

5.1. Increase in integrated approaches: ecology as the missing piece?

With a socio-technical ecology approach as our foundation, we noticed that research on energy systems in sustainability-profiled districts in Sweden has been mainly approached from a socio-technical systems understanding. Social components are increasingly conceptualized and integrated into the theoretical understanding of urban districts and energy systems. Also, research has been more observant and encompassed how different components connect, thus providing research results that provide a more complicated picture and comprehensive understanding of the development of energy systems in sustainability-profiled districts. The literature draws on several disciplinary and interdisciplinary research fields, for example, performativity theory [56], Feinstein's just city framework [120], (smart) urban metabolism [63,64], and the elusive concept of sustainability [56,57]. However, energy systems rely heavily on ecological resources which are often not explicitly included in the analysis [126]. Only three of the articles included in this literature review considered place-specific ecological circumstances [10,67,117]. A socio-technical ecology approach positions nature and ecology as foundations for all human activity and resource use at a specific geographical place [121]. Ecology and nature seem almost non-existent or at least a background in the included articles, while technology and human activities are brought forward. Studies focusing on the district scale could potentially be well-suited to include ecology and nature, as the limited geographical scale would facilitate empirical studies of a well-defined place. The decentralized urban planning system in Sweden also provides opportunities to consider local conditions when planning, developing, and evaluating energy systems in urban districts. However, as concluded in research theme 4, careful consideration of the effects of innovative energy systems on existing systems is needed. New developments must be firmly anchored locally when it comes to ecology: arable land, freshwater, local wildlife, and their habitats. The current lack of ecology and nature in research on energy systems in urban districts might have to do with how widespread theories and concepts are about these matters. While the term *exergy* [75–78,82] is represented in the reviewed articles, the comprehensive concept of *emergy* is only mentioned in one article [78]. *Emergy* could be used to indicate how labor-intensive and economically valuable a specific energy unit would be since it considers the impacts and dependency on the environment. For example, Western Harbor in Malmö used less labor-intensive geothermal heating for residential thermal comfort. Using electricity, a labor-intensive energy type, for heating would be wasteful from an *emergy* perspective. *Emergy* helps to understand the implications and impacts of different sources of energy, such as biomass, biofuels, wind, and solar energy. *Emergy* considers thermodynamics, system theory, and system ecology [20,127,128]. Based on this notion of ecology, ecosystem services have recently been included in Swedish urban planning and development [10,129] and eventually, more academic studies on energy as an ecosystem service at the urban district level will appear, see for example [10]. From a socio-technical ecology approach, the place-specific ecological prerequisites,

as well as the cultural, economic, social, and technical ones, need to be taken into account for a comprehensive analysis of human and economic developments [19]. This is in line with many of the future research areas found in this literature review, which point towards a more integrated and holistic understanding of sustainability and energy systems in the local context, including for example lifestyles, affordability, and inclusion aspects, but also local energy supply, and integrated electricity and heating systems. Recent developments in sustainability theories have also found ecology as a missing piece, while socio-technical issues are well-represented [15–18].

5.2. Relations between scales, phases, and impacts: the potential of the arena perspective?

The literature review shows that for the planning and development of energy systems, the district scale is seen as the intermediate scale between the household and building scale and the larger scale such as city or country, allowing a wide variety of stakeholders to contribute to the planning, development, and evaluation of sustainable energy concepts. However, a narrow focus on the district level has been criticized in multiple articles. Williams [61] states that new strategies for circularity on the district scale ask for closing resource loops at different scales, from global to local. Kopljar [68] shows that global, national, and regional (sustainability) initiatives have implications and consequences on the district scale and that it is important to pay attention to the interrelations between scales. The article stresses that there is a need for further research to address “the relationship between the scale of a sustainability problem and the scale of the proposed remedy for that particular problem” [[68], p. 222]. Shahroki and Bandt [62] describe that different questions require the use of different scales. The coordination of scales is also emphasized in the context of policy instruments and governance since political interest and governance support [95,111,117] and alignment of policy instruments from different levels are inevitable for the successful implementation of energy ambitions in urban districts [46,116]. The need for a multi-scalar perspective for sustainable energy systems on the district scale is also highlighted in the literature on consumption-based emissions in research themes (4) and (7) [57,64,71,96]. Until now, there has often been a selective view of how emissions are accounted for at the district scale, but the consumption-based perspective requires emissions to be accounted for in conjunction with other scale levels outside the geographical boundary of the urban district, meaning all emissions attributable to the user consumption patterns, wherever they occur [57]. Olson et al. [96] showed that in Sweden “the consumption-based emissions are twice as large as the territorial emissions and even higher in high-income areas such as Hammarby Sjöstad” [[96], p. 3].

The articles in this literature review demonstrate that not only the results and outcomes of the development of the districts but also the processes of energy systems planning, development, and follow-up themselves have been investigated over the past decades. Both the development process (including the political decision, urban design, building design, and construction phase), and the use of the district (including the follow-up, evaluation, and maintenance phase) have been examined in research on energy systems in urban districts in Sweden. Several research themes emphasize the early phases of urban development processes for more sustainable energy systems [97,103,105,106] e.g., for mapping or simulating solar energy or for early and broad inclusion of stakeholders. Although construction practices, next to the early phases of urban development, have an impact on the sustainability of energy systems in urban districts [8,75,109], we see limited attention to the construction phase. Only Glad & Gramfält [109] and Smedby & Quitzau [8] have considered the construction phase in the context of building practice and energy systems. Concerning the other planning phases, time dimensions have been explicitly addressed to understand changes in the development processes over time [56,112], to analyze thermal comfort categories over the course of the day [102], and in

relation to the temporal boundaries of emissions [63,65,71,75]. The studies on emissions show that dynamic and high-resolution data can help to expand the understanding of time as a process by going beyond the static indicators and providing continuous opportunities for feedback, understanding, and evaluation. Including users in energy systems research, by assessing indicators such as user comfort conditions [82] and behavior [84] or by understanding the roles, agency, and perspectives of users [111,117,120], also asks for better connections between phases.

The observations about space and time in the literature review align with the socio-technical ecology ideas of Hägerstrand [121] and his understanding of the relations between scales, processes, and impacts. He points out that “decisions and actions having distant impacts” [[19], p. 692] and identifies “the necessity of understanding the spatiotemporal context of the various actions in the landscape, actions that ultimately create positive or negative outcomes for the total environment” [[19], p. 693]. From this literature review, we see that in research on energy systems in urban districts, time is increasingly recognized as an integrated process and space from a multi-scalar perspective. Hägerstrand understands time and space as a shared arena in which people interact with other individuals, agencies, and institutions as a meeting point between the economic, social, cultural, technical, and environmental worlds [26,130]. Stenseke et al. described that “an arena perspective helps to describe and analyze the bigger picture that has to be considered” [[21], p. 90]. An arena does not stand on its own, as arenas interact and interrelate and must be understood as part of a greater whole, affected by different forces [20]. In our view, an arena perspective offers interesting components and ideas to further develop an integrated understanding of time and space for energy systems planning, development, and evaluation research. Two articles in this literature review used the concept of arenas which could serve as a basis to further explore an arena perspective in energy systems research [41,100].

6. Conclusion

This semi-systematic literature review provides an overview of the current state of knowledge about the planning, development, and evaluation of energy systems in sustainability-profiled districts in Sweden. The review of 70 journal and conference articles, published between 2003 and 2021, reveals that energy systems have been researched in 13 sustainability-profiled districts in Sweden, with Hammarby Sjöstad in Stockholm, Western Harbor in Malmö, and Royal Seaport in Stockholm as the most studied districts. The literature review shows that research into energy systems planning, development, and evaluation in urban districts in Sweden is fragmented but extensive. We have identified seven research themes in the reviewed articles: (1) Conceptualizations and critique of sustainability-profiled districts, (2) Evaluations of energy goals and requirements, (3) Technical and economic assessments of heating and electricity systems, (4) Integration of innovative (energy) solutions in urban planning, (5) Stakeholder perspectives on energy systems, (6) Stakeholder collaboration on the building and the district level, (7) Governance and policy instruments for sustainable urban development and energy systems. The themes illustrate the interdisciplinary nexus of energy systems and sustainability-profiled districts. With this literature review, we contribute to the current literature by providing a better understanding of the interdisciplinary topic of energy systems planning, development, and evaluation in urban districts in Sweden. We used the theoretical understanding of socio-technical ecology to critically discuss the body of literature reviewed in this article. From a socio-technical ecology approach, the place-specific ecological prerequisites, as well as the cultural, economic, social, and technical ones, need to be taken into account for a comprehensive analysis of energy systems and urban development. By taking a socio-technical ecology approach, we found that research on the Swedish sustainability-profiled districts provides directions and lessons learned

for both future research and future planning of (local) energy systems, inside and outside of Sweden. Research on the Swedish districts shows an increase in integrated approaches across all identified research themes and the importance of understanding the relations between scales, phases, and impacts. From these observations, several overarching directions for future research have been identified:

- Developing new or better-adapted energy indicators that increase the knowledge and agency of all stakeholder groups involved in the planning, development, and evaluation of energy systems, such as exergy per capita, comfort conditions, or dynamic energy use.
- Understanding the inclusion, perspectives, and roles of (new) stakeholders in the planning, development, and evaluation of energy systems in urban districts, such as users, stakeholders from the transport sector, or decentralized owners, and finding forms of collaboration, modes of governance and business models.
- Extending the socio-technical approach by including ecology and nature in research on energy systems planning, development, and evaluation on the district scale, by using the concepts of energy or ecosystem services for energy for example.

We believe that future research on energy systems in urban districts will benefit from a socio-technical ecology approach for a comprehensive understanding of the relations between scales, phases, and impacts, and how the economic, social, cultural, technical, and environmental worlds interrelate and depend on each other. To further explore the increased integration in energy systems planning, development, and evaluation, we propose to use an arena perspective as a metaphor and explanatory concept that allows for the inclusion of multiple perspectives and approaches. This review showed that recent literature is already moving in that direction.

CRedit authorship contribution statement

Janneke van der Leer: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Alexandra Calvén:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Wiktoria Glad:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision. **Paula Femenias:** Conceptualization, Writing – review & editing, Supervision. **Kerstin Sernhed:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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