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District Energy Viewed from the New Bauhaus Initiative Perspective—Sustainable, Inclusive and Aesthetic Heat

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Abstract: (1) Background: To support the energy transition in Europe, the EU has launched multiple initiatives. Supporting the "Green Deal" is the New European Bauhaus (NEB). District heating and cooling (DHC) is an important part of a decarbonized European energy system, and its role in the transition has been stressed by the EU. In this paper, DHC is, for the first time, reviewed assuming the NEB principles. (2) Method: a literature review combined with a review of three cases was used for collecting data. (3) Results: It is confirmed that DHC has strong sustainability values. It is also identified that DHC can become increasingly inclusive by adopting updated digital platforms and new technologies for heat recovery that necessitate close customer interaction whilst recovering waste heat. The least exploited principle is aesthetics. It could sharpen city planning by combining energy system and energy efficiency perspectives, increase the practice of multifunctional buildings (for example energy provision and recreation), and foster a closer interplay between architecture and energy. (4) Conclusions: for both innovating and expanding DHC, the NEB principles can serve as catalysts.

Keywords: district heating and cooling (DHC); New European Bauhaus (NEB) principles

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1. Introduction

1.1. District Heating and Cooling and the New European Bauhaus Principles

Heating and cooling are the largest energy sectors in the EU and represent half of the final energy consumed. The heat demand of the European building stock is 10 EJ per year [1]. According to the EU strategy on heating and cooling, district heating and cooling (DHC) are important technologies to decarbonize Europe. DHC involves a locally available energy supply, which is distributed to customers through a network where either heating or cooling is provided. Depending on the origin of the energy source, the heat supply can have a larger or lesser impact in terms of emissions. If the energy is generated by the combustion of fossil fuels, it will have a large impact, whereas if it comes from, for example, an industrial or urban infrastructure process, as waste heat, it might have no impact at all [2]. In spite of its advantages, only approximately 9% of the European heat demand is met by district heating (DH) [3], and the volumes of district cooling are much smaller. Accounting for the climate crisis [4] in combination with the geopolitical impact on energy supply in Europe, it is evident that DHC has gained greater policy support since 2022 [5].

The EU has an ambition to make Europe the first climate-neutral continent. To achieve the two-degree climate target by 2050, "clean energy investments" for the EU have been identified in the range of EUR 11,200 billion between 2021 and 2030. To finance the transition, the EU has adopted initiatives under the umbrella of EU sustainability policies to shape the regulatory and financial framework for the transformation of the real economy

and the associated decarbonization under the umbrella of EU sustainability policy. The "Green Deal" targets a number of sectors and actions, and several target energy supply [6]. To connect the Green Deal to the living spaces and experiences of European citizens, the European New Bauhaus (NEB) was initiated in 2020 with the ambition of creating beautiful, sustainable and inclusive places, products and ways of living [7]. The initiative is to propel transdisciplinary implementation of urban development, and the idea is to re-imagine how society can be transformed through the co-creation of multiple values.

The NEB initiative is based on three pillars: sustainability, inclusion and aesthetics. Sustainability (referred to further in this research as the sustainability principle) is wide and ranges from climate goals to circularity, zero pollution and biodiversity. Inclusion (referred to further as the together principle) promotes diversity, accessibility and affordability. Aesthetics (referred to further as the beautiful principle) stresses the quality of the experience and of the style beyond the functionality of the design [7].

Utilizing locally available energy sources, adjusting the heat supply, cleaning flue gases and investing in biodiversity actions (like beehives and stonecrop roofs) DHC can be fitted into the sustainability principle [8,9]. District energy is based on large volumes, which can lower costs (supporting affordability) to the detriment of a diversified offer [5]. In terms of accessibility, district energy is only possible if a building is connected to a network. There are, however, other "together" factors, using locally available heat/cold sources, promoting the energy exchange between buildings and heat/cold producers (in newer DHC systems at low temperatures), but also providing added quality of life to citizens by means of heated walkways/sports fields/driveways in wintertime as well as through educational efforts in the local community [10,11]. As demand response and flexibility use are increasing through the larger penetration of digitalization technologies, DHC may also support the development of local energy markets where collective actions in the form of energy communities arise [12–14]. Hence, some of the aspects of the together principle seem applicable to DHC but not all. When it comes to matters beyond functionality, like the quality of the experience or how visually appealing a DHC system can be said to be 'beautiful' by being partially invisible (pipelines below ground), and there is the potential to provide an aesthetic citizen experience through building and neighbourhood integrated design.

As there is a strong trend of increased DHC application in many EU countries, accounting for and explicitly presenting the future compliance of the DHC networks with the NEB values and principles may provide more arguments for quicker uptake of DHC networks. Aesthetics, increased sustainability, inclusion and affordability are not yet standard in the requirement profile of DHC networks, but they could add value to the existing technical, economic and environmental criteria for planning new DHC networks.

1.2. The Research Questions

No earlier study has assessed DHC through the lens of the NEB principles. Since the DHC sector has been identified as important to the energy transition, it is relevant to identify if the NEB initiative, at an overall level, is relevant to the DHC sector. On the one hand, it is important to understand if/how the NEB principles can support DHC expansion. On the other hand, it is important to understand if DHC can contribute to the implementation of NEB initiatives outside of the DHC sector. To shed light on this topic, three research sub-questions have been formulated:

- Question 1: Is DHC a relevant component of the NEB initiative?
- Question 2: Can the NEB principles be used to increase the uptake of DHC?
- Question 3: Can the uptake of DHC contribute to additional uptake of NEB initiatives and values/principles?

The next sections describe the used Materials and Methods (Section 2) as well as the Results and Discussion of these (Section 3), and the general conclusions are drawn in Section 4.

2. Materials and Methods

The first time that a topic is studied, it is important to combine data sources. Hence, in this paper, multiple methods were combined. First, a systematic literature review was conducted. As part of this work, an analysis of the documents submitted to the EU NEB website through various calls for information was also undertaken (access to documents was granted by the European Joint Research Center (JRC)). Second, relevant stakeholders were interviewed from three critical DHC case studies (best practice cases) from Sweden, Spain and Belgium. Last, to validate the findings from the literature review, the NEB website assessment and results from the interviews, the findings were presented in a webinar with DHC stakeholders, where insights and data were collected from the interaction with the audience. The methodological steps are presented in turn below.

2.1. Literature Review and Keyword Analysis on DHC and NEB Principles

A literature review was conducted to compile the existing knowledge on the inclusivity, aesthetics and sustainability aspects of DHC. The selected scientific databases were Scopus and Web of Science, complemented by Google Scholar and the inclusion of grey literature, such as government reports, EU reports and experience from EU-funded projects. Scientific literature was extracted from the databases using search terms containing keywords identified as relevant to one or several of the New European Bauhaus principles. The first search iterations were broader, while the later search terms were able to capture more specific aspects of the principles. All keywords and combinations are presented in Table A1 in Appendix A. The search results were scanned and included if they contained the selected keywords, addressed the desired topic and were published no earlier than 2015. Key literature studies identified in the reference lists of more recent articles were exempted from the timespan criterium. Once collected, the information from the articles and other literature that met the criteria was extracted and summarized to partially answer the research questions.

The keywords applied in the literature review were further used to analyse the contributions from the public and stakeholders to the New European Bauhaus "co-design" phase. During this phase, EU citizens were encouraged to share ideas and examples and to present challenges associated with the pathway towards beautiful, sustainable and inclusive living and built environment [15]. The keywords were used to analyse the contributions using a script in the statistics programming language R. The algorithm searched for one word per run, and the search terms were therefore split. The resulting number of occurrences and the number of files in which they occurred were compiled and presented as output from the script. The contributions identified to contain one or multiple keywords were studied in depth.

The search strings applied and the results from the exercise are presented in Appendix A.

2.2. Critical Cases

To address the heterogeneity of NEB values and principles in DHC networks, an analysis of three relevant case studies was conducted to complement the findings in the literature review with in-depth information. Three case studies were chosen so that aggregated information would contain broad information on the NEB principles integrated with DHC. Case studies were selected based on the following criteria: the size of DHC installation, construction decade, ownership and operational structure, and being active in district heating markets of various maturity levels. The selected case studies are seen as forerunners, in their countries, in implementing one or a multiple of the NEB principles and are assessed as critical cases from which the wider DHC sector can learn [16]. One case study was found in a mature district energy market, Sweden. Mature district energy markets were built decades ago when aspects like inclusion and aesthetics were of lower importance than reliable energy supply and sustainability. As a result of progressive and ambitious work to develop district energy activity, the case can even so shed light on all

three NEB principles. Two case studies were found in new district energy markets, Spain and Belgium, and as a result of city transformation activities also shed light on the three NEB principles.

For each case study, a literature search was performed using publicly available sources to provide background information about these cases. Thereafter, semi-structured interviews were performed in May–June 2022 with key stakeholders to assess how DHC networks are integrating the NEB principles. An interview guide was developed prior to the interviews (Appendix B). The guide was built around the three NEB principles, Beautiful, Sustainable and Together. The duration of each interview was approximately 60 minutes and the interviews took place digitally. During the interviews, either the interviewer or an assisting interviewer took notes that were returned to the respondents for validation. A total of eight interviews were conducted with 14 respondents with the aim of capturing the perspective of DHC from the city, the district heating operator, and the customer.

A short description is provided of each case study, including the motivation for how the case connects to the Bauhaus principles. Table 1 provides an overview and comparison of the case studies.

Table 1. Overview of the case studies included in the study.

Case Study	Ownership Structure	Size	Heat Market Maturity	First Construction	Main Bauhaus Principle
Stockholm (Sweden)	Public or private-public	Large (~1,000,000 residents)	High (~50% market share)	1950s	Sustainable
Torrelago (Spain)	Private	Small (~4000 residents)	Low (~1% market share)	1970s (Renovation 2017)	Beautiful
Ghent (Belgium)	Cooperative	Small (~300 residents)	Low (~3% market share)	2010s	Together/inclusive

2.2.1. Case 1: Stockholm (Sweden)

Stockholm is a city with a long DHC tradition. It is a particularly interesting case study to learn more about connections between DHC and neighbourhood aesthetics, and between DHC and sustainability. Stockholm is frequently assessed as being among the most beautiful cities in Sweden. Stockholm is also a large, dense city with extensive public transport and overall sustainability. Stockholm, the capital of Sweden with a population of almost one million in the city, has the highest population density in Sweden. Four DH companies are active in Stockholm, and their DHNs are increasingly connected to enable collaboration for the optimization of production. Stockholm has the world's largest DC, and 80% of the population receives heat from the DHNs. The remaining heat supply is mainly electricity. The DH market in Sweden is mature with an approximately 50% market share. In assessments of the most beautiful city in Sweden, Stockholm qualifies at the top, making it an interesting case study to learn more about DH's connection to sustainability and the aesthetics of a neighbourhood. Stockholm was named the first-ever European Green Capital (2010), and the city of Stockholm has ambitious targets to be a fossil-free and climate-positive city by 2030, and its DHN is aligned with these targets. It includes sustainable sources (heat pumps, waste heat sources from supermarkets, industry, seawater, sewage plants, etc.). The inclusion of waste heat will be enhanced in the future. In case waste heat sources are not enough, plans are to build a carbon capture and storage system on a biomass-fuelled CHP plant (BECCS). Other sustainable principles, such as circularity and biodiversity, are included.

Four interviews were performed for the Stockholm case study. In Stockholm, there are four DH companies, three of which were interviewed (one respondent from one company, two from another company, and three from the third company). One of the DH companies is co-owned by the city and therefore also represents the municipal perspective. The fourth

interview was with a large property company in Stockholm that represents the customer perspective. The key information on the case are summarized in Table 2.

Table 2. Summary sustainability principle Stockholm.

Case Study	Sustainability Impact on City Goals	Circularity	Biodiversity	Retrofitting	Other Principles
Stockholm (Sweden)	Sustainable sources. Aligned with city goals and companies involved in city plans	Recovery of waste heat (data centres, waste streams, etc.). Pre-sort waste management	One company involved in optimization of bio ashes to allow reforestation. Carbon emissions compensation through forestry projects	One company encourages through price incentives (heating bill). Other company offers the service	Citizen experience (heating statues that are local landmarks). Aesthetics (urban integration, multipurpose sites). Engagement of citizens. Tariff incentives.

2.2.2. Case 2: Torrelago (Spain)

DHC is a new technology in Spain, which is a new district energy market. In Torrelago, there is one DHC network operated by an energy service company (ESCO). In 2013, the district of Torrelago was chosen as a demonstration case for the European project Cityfied. Comfort was improved, mainly due to insulation improvements and façade renovations of buildings but also due to improved continuity and flexibility of supply from the DHC network. The DHC company in Torrelago has a high level of engagement with the residents and has included them in the decision-making process. This demonstrator provides insights into how DHC, sustainability, aesthetics and inclusion can be complementary dimensions. The district of Torrelago with around 4000 residents belongs to the city of Laguna de Duero in Spain. The district was built in the late seventies as a result of urban sprawl, characterized by a great expansion in a short period of time. The erection of the buildings had a practical and effective focus rather than integrating sustainability aspects. The district has recently been modernized with extensive retrofitting of buildings and improvements in aesthetics in the neighbourhood. Old boiler rooms that were located at ground level in an annexe building have been replaced with facilities located underground covered by greenery to promote its integration with the urban environment and improve the visual impact of the energy supply. The district has become more sustainable through the transformation and can offer more affordable heating to its residents. The DH market in Spain has low maturity with an approximately 1% market share.

For the Torrelago case study, a representative of the ESCO and the president and secretary for half of the building community were interviewed. The key information on the case are summarized in Table 3.

Table 3. Summary of beautiful principle Torrelago.

Case Study	Integration in the Cityscape	Reduce Use of Land	Biodiversity	Citizen Experience	Other Principles
Torrelago (Spain)	DHN does not affect cityscape, as DHN is integrated with the buildings, making old individual chimneys disappear.	Systems are hidden underground. Old DHN plant was buried	Integration of the DHN plant with greenery	Digital solutions provided to inform citizens. Citizens were part of decisions during the renovation works. Study visits to the plant	Fuel mix with 80% of local biomass. Positive impact on city goals. Increase in biodiversity and increase in retrofitting (windows, roof insulation) to reduce bills.

2.2.3. Case 3: Ghent (Belgium)

The 20th-century neighbourhoods on the outskirts of Ghent (Flanders, Belgium) are a potential laboratory for various sustainability challenges and transitions: quality and affordable housing, densification and open space, social inclusion and diversity, migration and integration, accessibility and mobility, environment and health, greenery and biodiversity, etc. The area De Nieuwe Dokken has undergone a metamorphosis and has been given a new purpose thanks to several new neighbourhood projects. It includes a cooperative that includes about 100 newly built residential units, located on the outskirts of Ghent in Belgium. This demonstrator sheds light on the three dimensions of sustainability, aesthetics and inclusion. Multiple actors are collaborating in the cooperative to supply residents in the area with district heating and wastewater services. The heat supply reflects circularity through the utilization of residual heat from industries and wastewater. The integration of solar panels with a battery is another example of how the case is working to improve sustainability. The case study is focused on supplying sustainable housing solutions at an affordable price and involving the customers as owners in the cooperative. All homeowners are given the opportunity to participate in the company as a house purchase comes with a symbolic share in the cooperative. The DH market in Belgium has low maturity with an approximately 3% market share.

For the Ghent case study, a representative of the DH company and three representatives from the municipality were interviewed. The key information on the case are summarized in Table 4.

Table 4. Summary of together principle De Nieuwe Dokken.

Case Study	Accessibility	Supporting Well-Being of Citizens	Energy Services to Citizens	Social Structure	Other Principles
Ghent (Belgium)	Energy company is accessible to citizens. Study visits are organized	Social cohesion activities. Active participation of local actors. End-user comfort is impacted positively by DH	Under development (e.g., heated bicycle lanes)	Cooperative project encompassing DHN actors, water and electricity actors	Use of waste heat; biogas produced on-site from organic waste. New greenery. Integration of DHN in city landscape. Public information elements

The interview guide was built to provide insight into each of the NEB principles. The interviews were analysed for each principle for each of the cases, and then, the three case analyses were aggregated to an overall result per principle. Now weighting between cases was performed to arrive at the aggregated result.

2.3. Validation Method—Stakeholder Workshop

To validate the analysed aspects from the DHC literature review, the NEB documents and the interviews of case studies, a stakeholder workshop was organized to collect data and feedback on the findings. Thus, the aim of the workshop was twofold: (1) to present the research results and validate them with the audience, (2) to ask for further recommendations and suggestions for accounting more concretely for the three principles of NEB (beautiful, together, sustainable) in the design, implementation and operation of district heating and cooling networks. In the workshop, the results were presented and discussed using an interactive tool (slido). The slido tool can include different types of polls, from which the word cloud and open question types were used. The workshop had an interdisciplinary group of stakeholders invited. Among the people registered (43 people, see Figure 1), there were representatives of the industry sector (heating system providers like heat exchangers, heat pumps, etc. and service providers, like energy meter providers, companies that develop energy management systems, etc.), DH companies, academia, municipalities, energy companies, associations, and, to a lesser extent, attendees from the construction, social housing, manufacturing and engineering sectors.

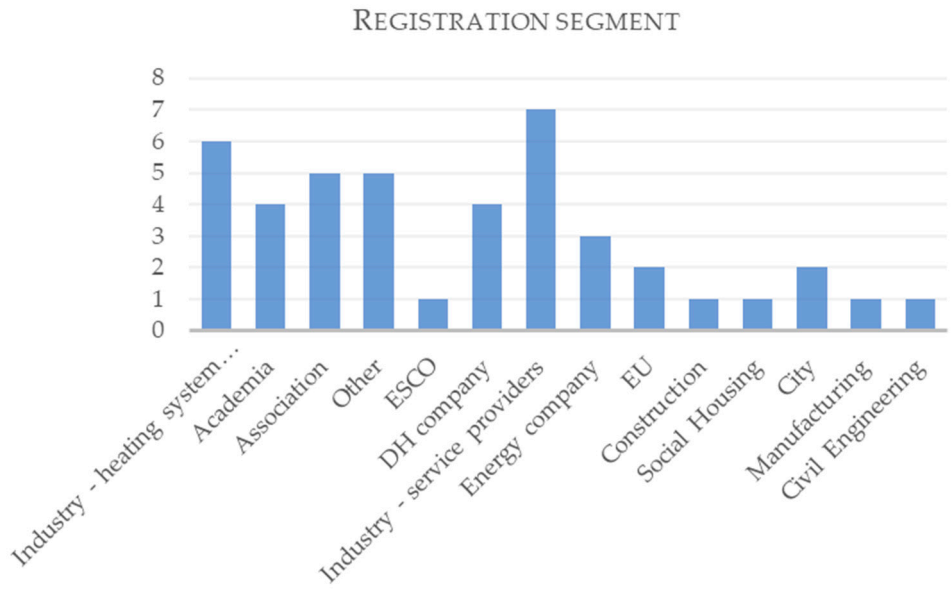

Figure 1. Registration segment for the validation workshop.

2.4. Limitations of the Chosen Methods

We have combined three data sources: literature, interviews and validation. Thereby, we have been able to identify the main results from different perspectives. Admittedly, three cases (14 interviews) is a limited number and additional cases and interviews would improve the accuracy of the results. Also, other methods of collecting data could give a deeper set of information. Surveys are a possible method for understanding the NEB principles in DHC, and conducting a survey of a larger population of DHC companies in more countries would increase the level of detail in the results. Our ambition is to make a first attempt to understand the DHC sector from the point of view of the NEB principles. Hence, we have deemed that a combination of literature review, critical cases and validation is sufficient to meet the purpose of our study.

3. Results

3.1. Results from the Literature and NEB Document Review

The relevant literature was considered from the past 5 years (2018–2022), as it was assumed that older sources would not be relevant to capture the NEB principles. Some references from 2023 have been added at the time of writing this article. The main results from the literature review are presented below.

3.1.1. Sustainable Principle

DHC networks are sustainable if the heat supply is not fossil. DHC promotes collective heating and cooling and can be more environmentally friendly than individual heating and cooling systems. The DHC networks of the older generations (2G, 3G DHC) still make use of fossil fuel, but their transition to newer DHC generations (4G, 5G DHC) [17] will make these networks more sustainable through the use of RES and locally available heat sources (with low or zero CO_2 emissions) [18], leading further to a better outdoor air quality in the neighbourhoods [19–22] connected to DHC grids and implicitly contributing to improved health and well-being of the inhabitants.

Key takeaways on sustainability: earlier research confirms that DHC systems are sustainable from the point of view of environmental impact (mainly due to lower air emissions).

3.1.2. Together Principle

DHC networks are strongly related to the together principle, where collective actions are encouraged. For NEB, which focuses on interdisciplinary initiatives, properly

cooperating with different DHC stakeholders from different backgrounds is and will be important, yet challenging, as in many countries DHCN penetration is limited. As new players enter the heating market and new business models are thought of and start being implemented, it is important to inform and connect DHC and NEB stakeholders [23] to enrich each other's domains and values. Properly mapping stakeholders per project phase and per linked sector/activity will be important to manage different stakeholders and ensure the potential synergies are captured. Furthermore, as the digitalization trend is also present in DHC, the use of digital technologies will allow better control and use of flexibility existent in DHCNs and the end user will become an important player in future cooperation models [24–26]. DHC energy seems to be affordable [17,27] for a large part of the population; however, the thermal energy tariffs are still connected with fossil fuel prices and may (during the phaseout period of fossil fuels) reach higher values. In most cases, the introduction of DHC as well as the associated digitalization requires some time for the inhabitants to get accustomed to the technicalities of the system, but the use of DHC systems is seen as easy and affordable [17,24]. Another feature supporting the together principle is the improved air quality mentioned above. It may also lead to more outdoor activities (sport, education, etc.) for the neighbourhood communities leading to an increased sense of belonging to sustainable communities. During the infrastructure/construction works needed to put a DHC network into the ground, there is an opportunity to provide preconditions for inclusive activities in the urban environment. For example, the creation of new green/public areas is possible along with sustainable mobility and transport in the neighbourhood. Indeed, initiatives like sustainable mobility and other green common initiatives like urban farming [28] or leisure space [29] can be promoted in conjunction with DHCN implementation.

Key takeaways on the together principle: A system approach is necessary for DHC network expansion. To install a system for a district, city or region, a large number of stakeholders need to interact. With digitalization, the inclusion of customers is increasingly facilitated, allowing the development of prosumers (heat customers that also provide waste heat into the system). Cleaner air can also lead to increased outdoor activity by residents, creating a sense of togetherness. In sum, the together principle applies both to the installation and operation of the DHC system, to the energy company–customer relationship and to the resident–community integration.

3.1.3. Aesthetic Principle

From the analysis of the DHC-related literature, many positive and negative examples of the aesthetic integration of DHC networks in the neighbourhood as a whole and in individual buildings associated with such networks were found. The typical DHC systems have a positive visual impact on the neighbourhood, at first because most of the DHC components, mainly the piping network, are hidden from sight [30] once they are in operation. Secondly, there are various options [31] to either bury the production and thermal storage units underground or to integrate them in the neighbourhood or in the buildings by creating novel aesthetic landmarks or educational/recreational hubs that lead to an enhanced sense of community, belonging and togetherness. Moreover, DHC networks, if deployed as planned, have a positive impact not only from the environmental and customer satisfaction point of view but also on the aesthetics of the community as a whole, by creating novel local landmarks [32] or by freeing up spaces on the ground, on the facades and on the rooftops (e.g., no need to install, for example, solar panels) of the buildings [24–33].

Key takeaways on aesthetics; DHCs contribute to city aesthetics by not being visible. An added value is that they free up space for, for example, green spaces Additionally, building multifunctional DHC sites is possible and can lead to new landmarks or recreational hubs that enrich the neighbourhood.

The key results are summarized per principle in Table 5.

Table 5. Key results from literature review (sustainability, together and beautiful principles).

Sustainable Principle	Together Principle	Beautiful Principle
Heat supply is the most important aspect of this principle	There is an opportunity to connect DHC and NEB stakeholders when new installations are to be made	The invisibility of pipes below ground is categorized as beautiful
Improved air quality is an added value apart from reduced GHGs	Digitalization of DHC will allow further end-user engagement	DHC buildings can be multifunctional and render new meeting points
	DHC is affordable	DHC systems free up space for, for example, green spaces
	Prosumers are made possible	
	Desire to perform outdoor activities in the local community (green spaces, urban farming, new art and leisure spaces)	

In sum, from the literature review, it is identified that the most acknowledged principle, sustainability, is confirmed. However, the NEB principles of together and beautiful are both pronounced but appear to be unexploited. This confirms that the contribution of this study is needed.

3.2. Lessons Learned on How the Three Case Studies Integrate the Bauhaus Principles

3.2.1. Sustainable Principle

The case studies show that DH has had, and continues to have, a positive impact on reducing climate emissions related to heating and electricity production. The key aspect historically has been the shift from fossil fuels to renewable energy sources, such as biomass, and waste heat. Examples of ongoing and future measures to further improve sustainability in the case studies are a sorting facility to remove plastics from waste prior to combustion, a bioenergy carbon capture and storage (BECCS) plant and sourcing of sustainable biomass to improve biodiversity. The establishment of DH in a city with individual combustion units has a positive impact on social sustainability for citizens as collective combustion improves air quality. The case studies show that DH is an enabler of circularity. The integration of waste heat sources into DHNs, such as sewage water, data centres, industries and supermarkets exemplifies the fact that that DH can utilize resources that would otherwise be wasted. The combustion of waste that would otherwise go to landfill for energy recovery is another example. The case studies indicate that more collaboration with the municipality and other stakeholders holds the potential to further enhance circularity in the city using DH. The DH companies in the case studies are not actively assisting or encouraging retrofitting and energy efficiency measures at the customers' buildings. There are, however, incentives built into the tariff structure of DH by charging the customer for the consumed energy, and increasingly customers are charged according to their peak consumption.

Key takeaways on the sustainable principle: DHC allows the phaseout of fossil fuels. It also can support to removal of the emission of GHGs from landfills. These features, in combination with the ability to recover waste heat, reflect that DHC installations can be strongly circular. Further circularity is possible if the buildings are made energy efficient.

3.2.2. Together Principle

The DH companies in the case studies are available to customers mainly through digital solutions and on the telephone. On digital platforms, customers receive information and can access data on consumption and invoices, but the platforms are not engaging or collaborative. The case studies in Spain and the Netherlands are working actively to involve customers in the decision-making process. The Dutch case study exhibits a high level of cooperation as the case collaborates on a larger scope of responsibility in the area, not only on heating, and customers are part owners of the cooperative. Public information elements

are mainly informative signs around the production plants, as well as organized study visits with various groups in the community, an area where the DH companies would like to improve, especially after the involuntary break in these activities during the COVID-19 pandemic. End-user comfort is considered to be increased in the case studies when a building connects to DH. A thermal heating system improves the indoor climate, and district heating is associated with a high security of supply. Once the building is connected to DH, it is considered that the district heating company can do little to impact end-user comfort; the only obligation is to maintain a constant supply temperature. During the construction phase of district heating, the impact on traffic is negative due to obstruction of roads. Once in place, DHCNs can assist with keeping bicycle and pedestrian pathways snow- and ice-free by providing ground heating, thus increasing accessibility for citizens.

Key takeaways on the together principle: DHC customers can be encouraged to engage in the DHC business by, for example, providing excess heat to the system. High comfort and security of supply are important aspects where DHC is a highly competitive alternative. Measures allowing increased inclusion of resident activity in the local community (take the bike in winter, green spaces) can be undertaken when systems are being built.

3.2.3. Aesthetic Principle

The aesthetics at the neighbourhood level are not impacted by DHC networks in the case studies apart from the invisibility aspect. Pipes are buried underground; the technical installations are in the basement of buildings, and the production plants are often located in neighbouring industrial areas. At the building level, DH-related buildings located in residential areas in the case studies showcase some best practice examples of cityscape integration. One example is a pump house that has been integrated into the hillside with wooden materials integrating it with the surrounding forest. Another example is a pump house where the roof is used as a recreational space. At the building level, DH requires less space than some alternatives and is located in the basement. The aesthetics of a building are also thought to be improved with DH installations as there are no visible external components.

Key takeaways on aesthetics: the invisibility of DHC is the main aesthetic feature and contribution to the cityscape. The multifunctionality of buildings can also be an aesthetic value.

The key results are summarized per principle in Table 6.

Table 6. Key results from interviews from three critical cases (sustainability, together and beautiful principles).

Sustainable Principle	Together Principle	Beautiful Principle
Heat supply and its emissions are an important sustainability factor. Carbon capture and storage are also relevant.	Digital platforms are important for end-user communication and engagement.	The DHC system is beautiful because the pipelines are hidden. Buildings can be integrated with the cityscape, allowing space to be saved.
DHC is inherently circular (allowing use of waste heat as well as avoiding landfills)	Cooperatives are the result of joint work; the together principle is explicit.	The building using DHC is more beautiful than a building with an individual solution attached to, for example, the façade.
Increased collaboration with local stakeholders can be further developed: it would allow for things like more efficient city planning	Study visits and visual information are commonplace to inform the greater society about the work performed at DHC sites.	The building using DHC can save space by having DHC installed in a limited part of the basement.
DHC company engagement in building energy efficiency improvements can be further developed: it would foster lower energy use and possibly also a closer relationship with building owners (together principle)	The most important factor for the end user is the indoor climate and security of supply.	

3.3. Results from Validation Workshop

The audience associated words with each NEB principle (sustainable, together, beautiful) with a neighbourhood, and with a DHN. In Appendix A, Table A2, the results are presented. The most repeated words related to DHC were "security", "sustainable", "comfort", "green" and "efficient". For the NEB, the associated words were "inclusive", "innovate", or "sustainable". A sustainable neighbourhood is related in a similar way to clean mobility, nature (green areas, trees, etc.) and low-carbon heat sources (renewable energy, clean air, solar panels, etc.).

A *sustainable DHC* network is one that is efficient (maximizes energy transferred from the network to the buildings in accordance with their heat/cold demand, is integrated with other grids, has reduced losses, etc.), sustainable (circularity, re-uses industrial waste/excess heat, no combustion, etc.) and has low-carbon heat/cold sources.

A *together DHC* and neighbourhood is related to open spaces (playgrounds, sports areas, shared installations, etc.), reduction in energy poverty (reasonable energy costs, socially inclusive and socially just/ethical), inclusion and communities (collective decision-making about common assets, and democratic collaboration between neighbours and various stakeholders in the DHC value chain to achieve win-win situations).

A beautiful neighbourhood considers mainly "nature" (and words such as green, green areas, garden, park, flowers or trees, associated with it), "playground" (or shared spaces), and words related to "mobility" (congestion free or bike paths). A *beautiful DHC* instead is associated with art, clean, architecture, and DHC systems that are visible or multifunctional.

The key results are summarized per principle in Table 7.

Table 7. Key results from stakeholder validation workshop (sustainability, together and beautiful principles).

Sustainable Principle	Together Principle	Beautiful Principle
Energy efficiency and low carbon are important sustainability factors.	DHC can contribute to new, open and green spaces.	Art installations, clean installations, architecture and multifunctionality of buildings are beautiful principle factors of importance.
Circular flows are important for sustainability	Energy communities and energy poverty are relevant factors to address for the together principle.	

At the end of the presentation of each NEB principle, the attendees were asked about ideas to potentially extend further the research work of this study. Some of the suggestions from the audience to promote the NEB principles in DHC included adding (digital) functionalities for citizens to improve communication and engagement (e.g., including transparent elements to visually show what is included inside a DHC element), adding more design/art elements to make it more attractive or communicating more effectively the benefits associated with DHC to all stakeholders, either by making citizens part of the decision-making processes or through the development of dedicated digital tools (e.g., apps).

Additionally, at the end of the webinar, the attendees were asked to provide their feedback through some final remarks and suggestions. In short, the participants agreed that the examples presented during the session were insightful and inspiring and that there is still a lot to be done in DHC in order to ensure a steeper uptake. Also, some topics were suggested to be included in further webinars, including energy communities in DHC, how to engage with citizens or providing more insight into the business model behind the relevant practical study cases.

3.4. Discussion

The DHC sector has worked to phase out fossil fuels since the oil crises in the 1970s, and over time, several complementary policy actions (like banning waste deposits) have brought the two items of emissions and inherent circularity of the DHC business case to the forefront of the sectors' strong sustainability contribution. This is something that the results of our study confirm. Lower attention to fostering stronger local dialogue (between DHC company and municipality for example) and direct DHC company involvement in energy efficiency matters in buildings leads to a development potential. This means that even the sustainability dimension can be strengthened by further engagement with customers, making buildings an integrated and active part of the energy system (as opposed to the current situation where the heat is delivered to the outer wall of buildings and often used in an energy inefficient way inside of the buildings as the building-level systems are prone to operational errors).

That indoor comfort and security of supply appear as important components of the together principle is not surprising. Heating and cooling cater for basic human needs. Hence, it is crucial that customers obtain a high-quality heating experience. There is no doubt that it is the greatest fear of professional building owners to receive complaints from tenants on indoor comfort, leading these points to be at the forefront of discussions between DHC companies and their customers. Digital platforms that are in existence and future (improved) ones are indicated to be important tools ensuring that DHC companies and end-users meet. Currently, there is still a practice of DHC companies communicating little but the monthly invoice to their customers, leaving room for greater improvement in inclusion. The particular ownership form of cooperatives is inherently strong in terms of the together principle. It can remedy the need to counteract phenomena like energy poverty or the need for an energy community. Whether such forms are applicable in all cases is however contested. New DHC technologies, utilizing locally available assets like waste heat from food stores or ice parlours, necessitate an increased collaboration between DHC companies and heat suppliers, something that is likely to foster prosumers (both providing and purchasing heat) who are engaged in DHC development. In a recent study of DHC business model 2050, it was identified that competitive advantage can be maintained in the long run only by co-creation with selected customers [34], which would indicate that there is still room for increased work on the aspect of collaboration to strengthen the together principle. This is further evidenced by the level of information provided about DHC activities to the wider society: information limited to study visits or visual information leaves room for closer and more forms of interaction with the wider community.

It is not often that being aesthetic equals not being seen. This, however, appears to be one of the strongest features of DHC solutions (pipes below ground). The production units per se are not much of a hindrance: they can be integrated into the cityscape or hidden. The fact that DHC solutions support buildings to remain aesthetic per se (not having to install any units on the façade) is an added value. If well planned, in dialogue with municipalities, DHC implementations can lead to the development of new recreational areas and aspects that heighten the quality of life (for example snow snow-free bicycle paths). The least explored aspect of the beautiful principle is that DHC can be combined with art, architecture and multifunctionality: possibly the principle that can have the largest impact on the future expansion of the DHC sector.

4. Conclusions

We return to the research questions and respond to them in turn.

Question 1. Is district heating and cooling (DHC) a relevant component of the New European Bauhaus initiative?

Yes, DHC appears to be a relevant component of the NEB. The strongest principle is sustainability, which was expected since the sector has worked for many years to reduce emissions and improve air quality in cities. There is, however, also a possibility to further

develop the sustainability principle by increasing local dialogue (DHC company and municipality) and by assuming an energy system perspective in tandem with energy efficiency first. The together principle can be developed further using digital platforms, new DHC technologies, new organizational forms (where applicable) and a wider palette of communication efforts to reach the wider society. The least explored principle appears to be the beautiful principle, where there are many new opportunities in city planning and art, architecture and multifunctionality.

Question 2. Can the NEB principles be used to increase the uptake of DHC?

Yes, the NEB principles can be used to increase the uptake of DHC. Based on the identified shortcomings of DHC under the different principles, it appears likely that collaboration with actors that can strengthen the together principle would lead to more initiatives of an energy community character, solutions for energy poverty, and wider acceptance of DHC technology in society. Complementary collaboration with actors that can boost the aesthetic dimension would be important, which could lead to joint art/energy installations supported by novel architecture and multifunctionality, possibly linking energy supply to recreation activities like green soccer fields, swimming arenas, ice parlours and others.

Question 3: Can the uptake of DHC contribute to more uptake of NEB initiatives and values/principles?

No, most likely the uptake of DHC can benefit from collaboration with NEB initiatives but not vice versa. The uptake of DHC in its current techno-economic framing will likely not contribute to the uptake of NEB initiatives. For that to happen, the conventional DHC stakeholders would need to engage in new stakeholder dialogue and interactions (with stakeholders focused on the principles of together and beautiful). That such collaboration would happen without policy measures or other incentives is not likely.

To conclude, our study sheds light, for the first time, on the applicability of the NEB principles to the DHC sector. We identify that further action can be undertaken to balance the DHC NEB principles. DHC has its strongest contribution under sustainability, a result of the core activity performed (to provide energy). To display a strength linked to the core activity is not unique for DHC. Rather it is representative of a large part of societal activity. Further inclusion of NEB principles in all city-level development activity is desirable for truly sustainable city development. The case of DHC shows that the inclusion of NEB principles would innovate the way that DHC solutions are designed and implemented. Furthermore, it could support further DHC uptake. In terms of policy implications, the result that NEB principles can support DHC expansion, it is important to increasingly stress NEB principles in the public procurement of new buildings. The public sphere can serve as a forerunner promoting NEB-adjusted DHC implementation to improve air quality, the inclusion of energy users in the local community and the aesthetics and functionality of energy assets. Waste heat is an asset with strong circular features, and public incentives to utilize this asset in the DHC context will strengthen the urban energy transition across Europe. Currently, there are incentives to utilize renewables like solar and wind whereas there was uncertainty around waste heat; was it equivalent to a renewable energy source or not? With the revised Energy Efficiency Directive of 2023, waste heat is for the first equal to renewables, allowing for public support to adopt this asset. By doing so, the sustainability, the inclusivity (of heat customers in the heat supply) and the aesthetics (removal of combustion units) of DHC will increase. Another note on policy is that municipal heat planning is becoming mandatory across the EU (cities larger than 50,000 inhabitants) as part of the revised Energy Efficiency Directive: a circumstance that can support the necessary development of DHC and municipal interaction. The energy efficiency principle supports building owners in prioritizing energy efficiency measures in their buildings. A shortcoming is that this focus can impede energy efficiency at the energy systems level if, for example, individual heating assets like heat pumps are chosen before system solutions like DHC. Hence, the closer interaction between energy efficiency policy and DHC expansion should be made mutually beneficial.

To further understand the capability of the NEB principles, it would be relevant to study them in other contexts than that of energy. Several consolidated studies would provide an indication of whether NEB can drive innovation in society at large or not. We acknowledge that the main shortcomings of our study are that it is a case study of critical cases in one industry. For further detail on the applicability of the NEB principles in the DHC industry, a wider dataset would have generated a deeper understanding. For further understanding of the NEB principles overall, additional industries—beyond energy—should be studied.

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Appendix A. Literature Review Screening Details

Table A1. Keywords used in search phrases in the literature review.

Keywords Targeting Aesthetic ("Beautiful") Aspects	Keywords Targeting Sustainability ("Sustainable") Aspects	Keywords Targeting Inclusicity ("Together") Aspects
"District heating" OR DH OR "district cooling" OR DC OR "district energy" OR DHC AND: • Aesthetic * OR esthetic * • "Aesthetic impact" OR "esthetic impact" • Beaut * • "Visual impact" • "Urban design" • "Use of space" • "Streetscape" • "Landscape design" • "Landscape architecture" • "Urban energy landscapes" • "Energy architecture" • "Nature-based solutions"	"District heating" OR DH OR "district cooling" OR DC OR "district energy" OR DHC AND: • "environmental impact" OR "environmental footprint" OR "life cycle" OR "life cycle impact" • (Environment * OR social) AND (sustainab *) • retrofi * • (retrofi * OR refurb * OR rehabili * OR renovat *) AND (synerg * OR confl * OR benef * OR effects OR impact) • "circular economy" • "fuel poverty" OR "social impact" OR "social effect *" OR "social aspects" OR health OR equity OR "urban heat islands" OR comfort • Mobility OR traffic OR road * OR street * • Urban • Spatial • Materia * • Polymer OR plastic * • ("life cycle analysis" OR "life cycle impact" OR "environmental") AND ("thermal storage" OR "electricity storage" OR "energy storage") • "environmental impact" OR "life cycle analysis" OR "carbon footprint" OR "environmental footprint" AND (distribution network OR "district heating grid" OR "district cooling grid")	"District heating" OR DH OR "district cooling" OR DC OR "district energy" OR DHC AND: • Thermal • Cooling • "Energy cooperative" • "Energy initiative" • Denmark • Germany • UK • "Clean Energy Package" • Interdisciplinary • "Sector coupling" • Flexibility • "Urban planning" • Participatory process • Norms • Values • Legislation • Socio-economic • Social • Economic • "District heating" • "New European Bauhaus" • Inclusion

Table A1. *Cont.*

Keywords Targeting Aesthetic ("Beautiful") Aspects	Keywords Targeting Sustainability ("Sustainable") Aspects	Keywords Targeting Inclusicity ("Together") Aspects
		• "Digital divide" • Diversity • Digitalization • ICT • "Smart algorithms" • Artificial intelligence • "Machine learning" • "Sector coupling" • "Energy poverty" • "Digital solutions"

* used at the end of a root word, referred to as "truncation", to search for variable endings of a root word. For example: searching for educat * would tell the database to look for all possible endings to that root. Results will include educate, educated, education, educational or educator.

Table A2. Script screening results.

Keywords from Task 1	Total Number of Occurrences	Number of Files Containing Keyword
aesthetic	208	47
artificial intelligence	14	7
bauhaus	629	63
beautiful	81	28
benefit	146	58
building	1146	95
built environment	283	38
circular economy	62	26
city	1494	120
collective action	2	2
comfort	65	24
cooling	113	11
digital solutions	1	1
digitalization	12	7
district	40	24
district heating	2	2
diversity	221	50
economic	451	78
effects	57	33
energy poverty	4	2
environmental sustainability	19	11
equity	18	13
flexibility	23	15
green areas	8	3
green building	11	3

Table A2. *Cont.*

Keywords from Task 1	Total Number of Occurrences	Number of Files Containing Keyword
health	234	57
heating	117	14
ICT	278	67
impact	284	84
inclusion	113	34
landscape architecture	11	5
landscape design	7	5
legislation	31	16
machine learning	11	2
nature-based solutions	9	5
neighbourhood	198	50
norms	11	6
participatory process	13	7
refurb	21	9
rehabilitation	31	10
renovation	152	37
retrofit	27	10
social	1101	103
social aspects	2	2
social effect	1	1
social impact	4	4
social sustainability	5	4
socio-economic	23	15
synergy	34	19
thermal	97	16
urban	922	79
urban design	50	11
urban planning	75	25
use of space	2	1
values	219	50
visual impact	1	1

Appendix B. Interview Template

Appendix B.1. Section Sustainable: Climate Goals, to Circularity, Zero Pollution, and Biodiversity (Account for Nature and Be Long Term)

1. What is the fuel mix of the case?
    - What is the heat mix foreseen in upcoming years?
    - Why is a change foreseen? What are the challenges?
    - How often is maintenance undertaken and how? What are the efficiency indicators?
2. Does the case have a direct impact on the climate goals of its city?
    - Does the case have a dialogue with the city about climate impact?
    - Are there shared goals with the city?

3. How does the case reflect circularity?
    - Water
    - Ashes
    - Waste to energy
    - How is plastic treated?
    - Residuals from forestry (biomass)?
    - Other
4. Is the case working with biodiversity?
    - Ecosystem services
    - Beehives/other improving pollinators
    - Supporting biodiversity in forestry
    - Other
5. Retrofitting
    - Does DCH support/counteract retrofitting of buildings
    - Does DHC necessitate retrofitting of buildings to be efficient
    - Can an efficient DHC system counteract necessary retrofits
    - Does retrofitting include public and private buildings? Or does one category dominate?

Appendix B.2. Section Beautiful: Quality of Experience and Style, beyond Functionality

1. Is the design of the district heating/cooling system integrated into the city?
    - Is it integrated into the skyline?
    - Does the design of the system integrate green areas for citizen recreation?
    - Does the DHN impact the streetscape? How? Pitfalls? Best practices?
    - Does the DHN construction phase negatively impact the cityscape?
    - Other
2. Is the design of the district heating/cooling buildings used for the citizen experience?
    - Lightshows on buildings
    - Display of information on energy from, for example, solar or waste heat
    - Covered with street art?
    - Does the design of the district heating building allow a combination of old and new?
    - Can refurbished buildings be transformed into art?
    - Is the user experience included already in the DHN design planning?
    - Other
3. Is the district heating/cooling company engaging in local produce?
    - Greenhouse
    - Supporting local forestry
    - Vertical farming
    - Energy recovery from waste
    - Waste heat recovery
    - Other
4. Is the district heating/cooling company providing educative elements in the cityscape?
    - Openings in the ground showcasing pipes
    - Message about biogas generation from food waste (on waste collection trucks or similar)
    - In collaboration with municipal communication?
    - Other
5. Does DHC impact the aesthetics/design internally/externally of buildings
    - Space needed for equipment
    - Placement of equipment (cooling/heating on outside wall)

- Other
- Is the DHC station used for multiple purposes?
- As a green area
- As an office building or cultural space
- Other

Appendix B.3. Section Together: Valuing Diversity, to Securing Accessibility and Affordability

1. Is the district heating/cooling company accessible?
    - Easy access to headquarters (in city centre or outside)
    - Educational efforts (hosting study visits)
    - Does the DHC encourage citizen engagement and collective actions?
    - Is the DHC advanced in terms of digital use (customer side and operation side)
2. Is the district heating/cooling company facilitating energy services for citizens' everyday life?
    - Ground heating in city centre (avoiding accidents and injuries in Winter)
    - Heated seating areas in city parks or other spaces like bus stops
    - Waste collection of particular waste, like for example Christmas trees
    - Other
3. Is the district heating/cooling company supporting the well-being of the citizens?
    - Annual charity events
    - Annual sports events open to the public
    - The "environment hero" of the year awards
    - Green/Blue networks in the neighbourhood (like aquifers)
    - Integration of sport/recreation facility with the network (ground heat under football fields/the ski slope in Copenhagen)
4. Is end-user comfort impacted by the choice of DHC?
    - Temperature stability
    - Impact individual energy use (is a motivational tariff in place)
    - Indoor air quality
    - Sound comfort (is the installation noisy)
    - Visual comfort (is the installation part of the cityscape)
5. What is the logic of the heat/cold tariff?
    - To be cost competitive to alternative heat supply
    - To optimize district heating network and production functionality
    - To establish shared incentive with the customer for increased energy efficiency
    - Is there any support for people who might suffer energy poverty?
    - Other

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