International Energy Agency Implementing Agreement on

District Heating and Cooling including Combined Heat and Power

Annex XI final report summary

Plan4DE: Reducing greenhouse gas emissions and energy consumption by optimizing urban form for district energy

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Executive Summary

Urban areas, accounting for between 71% and 76% of greenhouse gas (GHG) emissions (Seto & Dhakal, 2014), will be critical to efforts to decarbonize societies. Ongoing urbanization is projected to result in an additional 2.5 billion people living in cities by 2050 (United Nations, 2014), an increase which will require major investments in infrastructure. The form of this urban infrastructure, which includes buildings, transportation, energy and waste management systems, can either enhance or hinder efforts to reduce GHG emissions. Urban infrastructure is capital intensive and durable, and is therefore difficult to change once constructed, a phenomenon known as lock-in.

Local governments can either lock-in or lock-out opportunities for district energy, a low carbon solution, according to the pattern of development which they enable. If city planners do not consider district energy, proponents of district energy are limited to those areas that through historical accident have achieved a sufficient energy density. On the other hand, by targeting new development in specific areas, city planners can increase energy density and enable district energy.

This project has focused on supporting city planners in considering the impact of the built environment and urban infrastructure on district energy viability. A decision support tool, Plan4DE, was developed following an extensive literature review and using an integrated design process that combined the expertise of planners, engineers and architects. The resulting Excel-based model has three different interfaces for different use cases or practitioners with different levels of experience.

Plan4DE uses inputs on characteristics of the built environment to determine the capital and operating costs of district energy versus individual energy systems over variable lifetimes, as well as environmental impacts including GHG emissions and criteria air pollutants. Planners are thus able to employ Plan4DE to determine the viability of district energy relative to individual heating and cooling for a specific built form, and to optimize the design of the built form to increase district energy viability.

1 Introduction

Of all the energy-related decisions made at a community level, it is likely that land-use decisions have implications on the community's consumption of energy for the longest time. Physical infrastructure and the spatial organization of society can be seen as an important form of 'carbon lock-in' (Erickson & Tempest, 2015), the process by which society becomes further entrenched in a dependent relationship with fossil fuels. Land-use decisions therefore need to be prioritized in efforts to reduce energy consumption and greenhouse gas emissions, above transportation management, site and building design, and energy supply (Jaccard, Failing, & Berry, 1997).

In order to maximize the potential for district energy to contribute to reductions in greenhouse gas emissions, planners need to incorporate district energy as a consideration in the development of municipal plans, upstream from the actual development of the built environment (King & Bradford, 2013). Consideration of district energy at this early stage in the development process will build literacy on district energy in communities, result in enabling land-use patterns and create new district energy opportunities.

2 Methods

The intent of this project was to use novel research methods to design and implement a model that meaningfully represents the relationship between characteristics of the built environment and the viability of district energy. There is extensive research on this relationship, which was identified in a literature review; however, the novel aspect of this project was to facilitate the evaluation of the impact of the built environment on the viability of district energy from the perspective of a city planner, and to do so using a tool suitable to different contexts around the world. For the purposes of this analysis, district energy is considered viable when it is the economically preferred option for a particular context in comparison with individual heating or cooling systems in each building.

The construction of a model that is applicable for the discipline of urban planning, while incorporating aspects of the fields of systems modelling, architecture, urban design, civil engineering, energy systems engineering and economics, is by definition interdisciplinary. Building on past experience, the team elected to employ a technique developed in the design of high performance green buildings, the integrated design process (IDP) (Keeler & Vaidya, 2016). An IDP focuses on broad involvement of the different disciplines of the team in the initial design stages during which key decisions are taken that determine the outcome of the project. To this end, the team was convened for a three-day design charette to set the stage for the interdisciplinary collaboration that characterizes the IDP approach. The charette began at a high level with decisions on the goals and objectives, and became increasingly specific, as model parameters were identified, and ultimately initial efforts at model design and implementation were undertaken.

3 Modelling the built environment

“A model is not a piece of absolute and universal science but the expression of a point of view that will take place in a social context where it will more or less be relevant” (Bouleau, 1999, p. 340).

What is a model? In this project, a model is defined as a conceptual abstraction of an existing or proposed real system that captures characteristics of interest, consisting at its essence of inputs, calculations and outputs. There are two streams of modelling of interest to this project: urban energy modelling and district energy modelling. There is overlap across these two streams as those interested in district energy seek to characterize the heating and/or cooling demand of the built environment to investigate the feasibility of district energy, and those interested in energy flows within the built environment also seek to understand heating within buildings.

A model, if designed to address the capabilities and context of a user group, in this case city planners, can facilitate an enhanced understanding of cause and effect and therefore improved policy outcomes that support energy efficiency and greenhouse gas emissions.

In order to understand relevant modelling approaches and strategies, a scan of the existing modelling ecosystem was undertaken, focusing on the built environment, urban energy systems and district energy. There are many examples of different modelling strategies to support decision making related to district energy. No models, however, were identified that support planners in optimizing the built environment for district energy. The models available vary in focus, complexity and accessibility according to their positioning relative to their stage in lifecycle of the development of district energy. Plan4DE is uniquely positioned upstream as an intervention in the development of the built environment, prior to the articulation of a particular district energy project.

4 Plan4DE

Objectives were established for Plan4DE that are broader than the technical task of developing equations that illustrate the relationship between the built environment and district energy; they also address social determinants. Plan4DE was designed to be:

- **Persuasive:** Plan4DE clearly and simply communicates to planners, engineers and elected officials the benefits of urban form that support district energy, both in terms of the benefits resulting from district energy and co-benefits.
- **Cross-disciplinary:** Plan4DE builds linkages between disciplines including planners and engineers, and planners and politicians, by enabling and encouraging bridging discussions. As district energy is not the traditional remit of planners, planners are likely to consult or engage with engineers responsible for city infrastructure. As planning typically involves participatory processes and engagement of elected officials, a tool which integrates district energy into planning is likely to prompt discussions between planners, politicians and engineers.
- **Practical**: Plan4DE enables land-use planners, through iteration, to create a built form that is conducive to district energy, using language, concepts and practices that are directly relevant and applicable.
- **Enabling:** Plan4DE serves as a decision gate, a binary tool that describes whether or not district energy is viable for a specific combination and configuration of buildings, and then enabling a user to explore the variables that enable or disable that option.
- **Educational:** Plan4DE enables professionals who don't normally think about or consider energy to incorporate energy into their plans. It helps unveil the energy implications of land-use decisions to those making the decisions.

4.1 Model characteristics

Key characteristics of Plan4DE were determined during the design process. The model was designed for specific countries, with the potential to be expanded to other locations as a result of accessibility to data and the team's knowledge of those countries. In keeping with the imperative of influencing the design and development of the built environment, the model was designed to accommodate geographies that are common in the world of city planning; both the city and the neighbourhood. Consideration was given to both greenfield sites in which buildings are constructed on a blank slate, and existing built environments which are confronting change in the form of new developments or intensification. The audience for Plan4DE was identified as city planners and those who have a significant influence over the built environment.

There were many implications of these decisions for Plan4DE. The requirement to address broadly different spatial contexts (neighbourhood to city) in combination with the need for an accessible platform resulted in the decision to use Excel as the modelling platform, and to undertake spatial analysis separately in a GIS platform. Given that most planners have limited modelling experience, there was an imperative to ensure that Plan4DE was simple to use, with a concern that the richness of the model would be lost in the simplicity. As a result, three different interfaces were developed to enable its application with different levels of technical ability.

On a district energy feasibility trajectory, Plan4DE was defined as "pre-pre-feasibility"; pre-feasibility was defined as an initial scan to identify whether or not a feasibility study (a detailed assessment of the economic parameters of a project) is merited. As a pre-pre-feasibility assessment, Plan4DE is not concerned with the details of a particular project, but rather whether or not the existing or proposed built environment could be optimized to enhance the feasibility of a generic district energy system.

4.2 Analytical approach

The first task in applying Plan4DE is to define the district including its size, whether it is a greenfield or redevelopment project, how the district is configured, the number of buildings, the type of buildings and the density of buildings. These calculations can be performed in GIS or estimated according to the use case of the analysis. Subsequently, the reference case for thermal energy is defined; what technologies are used to heat or cool the buildings and with what fuels? The next step is to define the district energy system including whether technologies will be optimized according to cost, or whether specific technologies will be selected based on available fuels or policies. The economics of the reference case and the district energy solution are then compared; based on the results, the user can go back into the model to refine the characteristics of the district in order to improve the conditions for district energy or to test other variables.

4.3 Model design

Plan4DE was implemented in Microsoft Excel to enable broad access and easy adaptability. Figure 1 illustrates the model structure. A general framework includes catalogues of technologies and assumptions on prices and emissions. A district is defined in terms of buildings and a network. Constraints of various forms are applied to the technologies, costs, buildings and other variables based on the specific circumstances of a particular project. With the above considerations, the model calculates heat generation costs, network costs and the total heat supply costs. The outputs are a comparison of district energy costs versus individual heating costs, and environmental impacts in terms of air pollutants and greenhouse gas emissions.

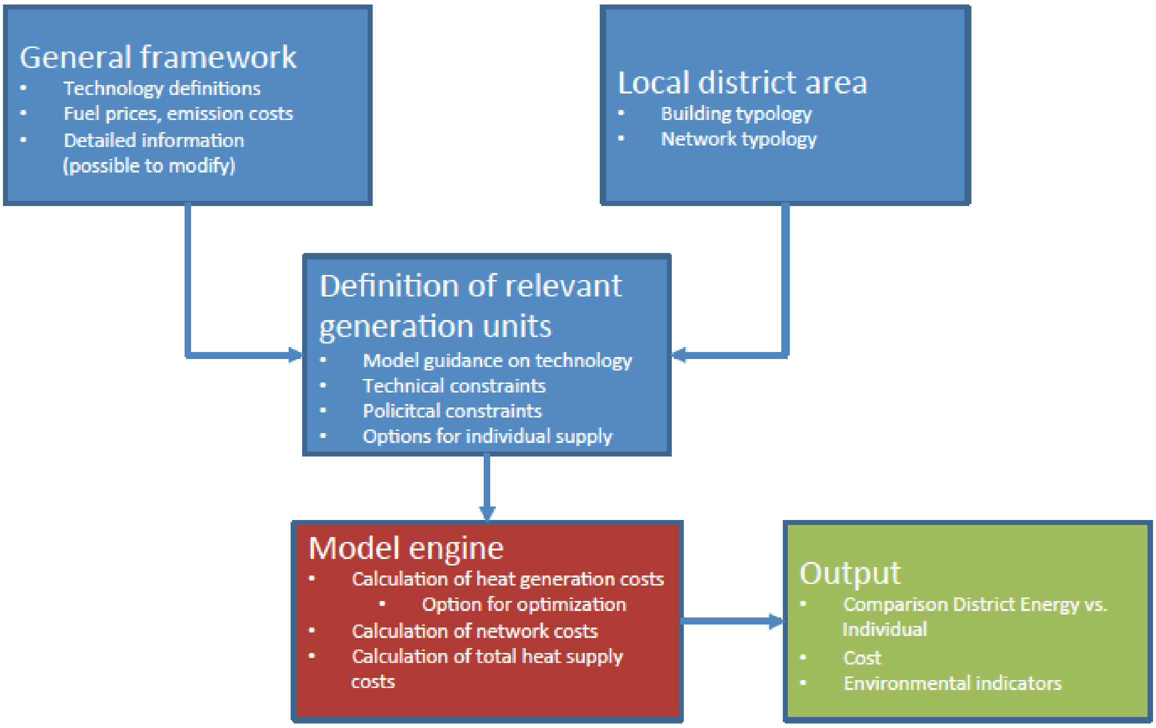

Figure 1: Model structure.

At the heart of the model is a cost curve for district energy, which is calculated for each district based on the optimization of technologies or user-selected technologies. The district energy cost curve is generated specifically for each configuration of the built environment, varying according to the optimal combination of district energy technologies required to supply heat for a particular combination of buildings. A second linear cost curve represents the cost of individual heating systems; this cost is held constant. The desirable outcome is to identify a heat density at which point the cost of district energy is lower than the cost of the individual heat supply.

5 Validation

5.1 Applying Plan4DE to a neighbourhood archetype

An archetypical neighbourhood was developed, based on an existing neighbourhood in Seattle, and Plan4DE was used to evaluate and inform development scenarios for that neighbourhood. A typical planning process was undertaken that incorporated analysis using Plan4DE.

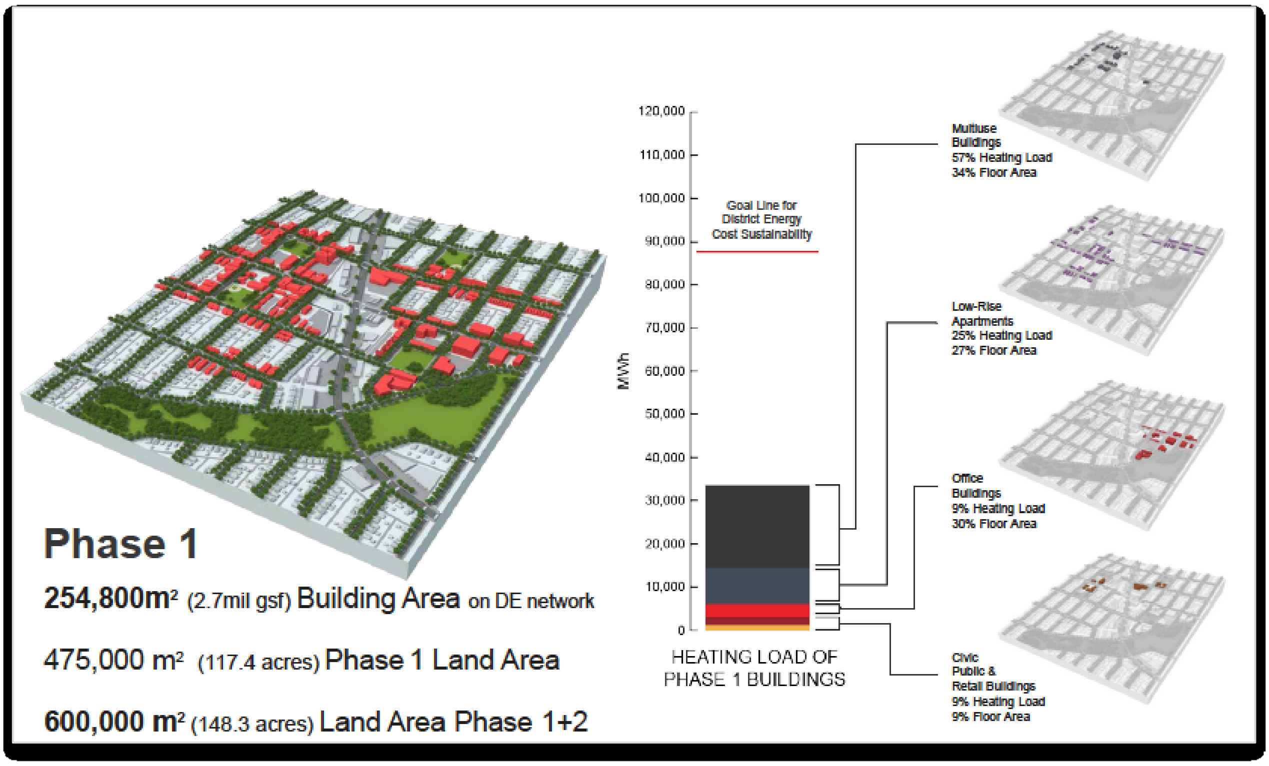

Figure 2: Evaluation of an archetypical neighbourhood using Plan4DE.

While the full build-out of the neighbourhood was found to be conducive to district energy, the first phase did not incorporate adequate heat density. In this case, the district energy developer would need to construct the district energy system taking a risk that subsequent phases would occur. If the developer waited for the development of the second phase, building owners will have already invested in individual systems. The conclusion was unequivocal that Plan4DE helped guide their decision-making to prioritise a built environment that would enable district energy, with a tool that was clear and understandable.

A subsequent and more detailed analysis was undertaken for neighbourhoods in the City of Ottawa using various data sets, including observed data. Heat density in

Plan4DE is calculated either by identifying the number of archetype buildings or by specifying the floor area associated with a building type. This analysis was intended to better understand the difference between the head demand predicted using these methods in Plan4DE and other methods, and observed data. There are a limited number of archetypes and building types in Plan4DE, which necessitates a level of generalization that enables ease of use for planners. The analysis indicated that the archetypes approach can vary significantly, as would be expected, in comparison with an approach that uses observed floor area by building type.

6 Dissemination

Dissemination was considered a critical aspect of the project, providing feedback and exposure that would inform the development of the model and ultimately determine the impact of the model in advancing district energy. A website was developed that enabled people to follow the development of the model, download documents and presentations, and follow webinars. Three webinars were held on the relationship between the built environment and district energy, the model design, and the relationship between planning and district energy. Plan4DE was presented at a number of events, most notably at the International District Energy Association conference in Boston (2015) and the United Nations Framework Convention on Climate Change in Paris (2015).

7 Conclusion

The findings of this project have confirmed the importance of the city planner in enabling district energy as a low carbon solution. A planner can influence density and configuration of buildings but can also provide for a location or locations of district energy centres. The imperative for engaging planners to consider district energy is clear.

The interdisciplinary nature of the team was critical to the outcome; the view of the planner, the architect and the engineer on district energy in concert was critical to developing a meaningful model that incorporated engineering principles from district energy design, but was accessible and relevant to planners.

A number of unanticipated outputs emerged from the project. One included a demonstration of an interactive web dashboard for one climate zone that enabled planners to test various combinations and sizes of buildings to identify a combination that favoured district energy. A powerful algorithm was created that calculates pipe length for a particular site based on the shape of the district energy system without a requirement for any spatial analysis. An optimisation tool was developed which identified the most cost effective generation capacity for specific heat load. Each of these sub-projects provided additional insight into the design and deployment of district energy systems.

While Plan4DE is not designed to perform as a feasibility tool, the validation process suggested that it could nonetheless play a major role in determining feasibility of district energy by contributing full cost accounting information to inform a business case. In conjunction with developing heat maps and spatially identifying areas with district energy potential, Plan4DE enables very quick calculation of total heat demands and heat densities for any identified area, as well as rapidly generating district energy system costs (for optimized or pre-selected technology and fuel). This enables planners to quickly determine the implications of any built form for district energy potential, and understand the impact of changing building or district densities on that potential.

Abbreviations

(in alphabetic order / only those present in the summary report)

CHP	Combined Heat and Power
DHC	District Heating and Cooling
GHG	Greenhouse gas emissions
IEA	International Energy Agency
IDP	Integrated Design Process
Plan4DE	Plan for district energy

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