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Cost optimal urban energy systems planning in the context of national energy policies: A case study for the city of Basel

Mashael Yazdanie*, Martin Densing, Alexander Wokaun

Energy Economics Group, Laboratory for Energy Systems Analysis, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

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ABSTRACT

With over 50% of the world's population residing in cities, urban areas have the potential to contribute significantly to global CO_2 emissions reductions through careful urban energy systems planning and community participation. However, urban policymakers must operate within the constraints imposed by national energy policies. This study aims to understand the impacts of different national energy strategies on long-term urban energy systems planning through a case study for the city of Basel in Switzerland. A cost optimization modeling approach is employed and heat and electricity demand sectors are considered. Energy efficiency measures, particularly building renovations, are found to be cost optimal and enable significant energy demand reductions. Decentralized generation and storage technologies, including rooftop PV, heat pumps, small gas CHPs, and batteries, also provide pathways to reduce emissions and improve energetic self-sufficiency in the long-term. Heat generation using municipal waste provides a cost optimal, low emissions generation pathway as well. Carbon taxes are found to have a significant impact on the uptake of low-emission technologies. The urban environment encourages policymakers to pursue strategies to reduce local CO_2 emissions across all national energy policy options evaluated, not only achieving, but also exceeding relative national policy targets in a cost optimal solution.

1. Introduction

Urban areas currently accommodate over 52% of the world's population, and account for over 70% of global energy-related CO_2 emissions (Edenhofer et al., 2015). Urban populations are expected to grow in the future, accounting for an estimated 70% of the global population by 2050 (Edenhofer et al., 2015). Given the magnitude of their impact, urban regions present an opportunity to mitigate global emissions and energy demand through local-scale energy system planning and policy initiatives.

Infrastructure planning in the built environment, in particular, is a strong driver of urban emissions and energy usage (Creutzig et al., 2016). Urban infrastructure also has longevity and inertia; that is, planning decisions today have impacts long into the future, effectively forming boundary conditions for future energy system planning (Creutzig et al., 2016).

While international agreements, such as the Paris Agreement, largely inform carbon mitigation pathways on the national level, individual cities may also exercise jurisdictional authority to advance sustainable energy system planning goals on a local scale. C40 Cities Climate Leadership Group is one such initiative, aiming to connect cities committed to carbon mitigation and sustainable city planning. C40 consists of a global network of more than 80 cities which together represent more than 600 million people and 25% of the global economy (C40 Cities, 2017a). The initiative calls on participating cities to take significant steps towards carbon mitigation by 2020 in order to achieve the emissions reductions needed to meet the Paris Agreement's target of a 1.5 °C long-term (i.e., until 2100) increase in the global average temperature compared to pre-industrial levels (C40 Cities and ARUP, 2015). The urban case study presented in this article focuses on Basel, a C40 member city.

As urban areas are being encouraged to adopt carbon mitigation measures (for example, through the uptake of low-carbon emission and high-efficiency technologies), it is also important for cities to gain an understanding of long-term, cost-optimal, energy system planning for their cities under different policy scenarios. Indeed, if the adoption of low-carbon, high-efficiency technologies and building renovations is shown to be both cost-optimal and at the same time effective in reducing emissions under national policy constraints, more cities could be motivated to adopt sustainable energy system strategies.

Abbreviations: BAU, Business-as-usual; DGST, Decentralized generation and storage technology; NEP, New energy policy

* Correspondence to: Paul Scherrer Institute, OHSA/E03, 5232 Villigen PSI, Switzerland.
E-mail addresses: mashael.yazdanie@psi.ch (M. Yazdanie), martin.densing@psi.ch (M. Densing), alexander.wokaun@psi.ch (A. Wokaun).

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Cost optimization energy system models and policy scenario studies also tend to focus on analysis at the global or national scale (for example, Amorim et al., 2014; Gago da Camara Simoes et al., 2013; Goldstein and Tosato, 2008; Pattupara and Kannan, 2016; Ramachandran and Turton, 2016); however, given the unique built environment of urban cities and their potential to contribute to global emission reductions, there is a growing need for such studies to be conducted on the urban scale, aiding policymakers in shaping municipal energy strategies. Yet, few urban cost optimization-based studies focus on the impacts of national energy policy variations on local scale planning as a primary objective.

The aim of this study is to investigate the impacts of different national energy policy strategies on long-term, cost optimal energy systems planning on the urban scale. The study also aims to understand how well national energy strategy goals align with the cost optimal solution for an urban city under exogenous national policy conditions. Modeling and analysis is focused on the Swiss city of Basel, one of the largest and most diversified urban energy systems in Switzerland, and the only Swiss C40 member city. A cost optimization energy systems model is developed which focuses on all major heat and electricity demand sectors in Basel until 2050.

The role of decentralized generation and storage technologies (DGSTs) in the future energy supply mix of Basel is also of interest under different national energy scenarios, as DGSTs potentially offer low-polluting and more energy- and cost-efficient alternatives to centralized generation and distribution technologies.

Although this study focuses on the Swiss case, a range of technology options are investigated for Basel which are relevant to urban energy systems planning in a broader context. Cities dedicated to sustainable urban planning in other developed countries, including C40 cities in Sweden, Denmark, and Germany for instance, can benefit from analytical insights regarding technology interactions, the local effects of more stringent national climate policies, and system sensitivities to regional cost variations.

2. Background

2.1. Urban energy system models

The paradigm shift in urban energy systems planning, driven in part by decentralized technologies, is discussed in recent literature. (Manfren et al., 2011) reviews several of the modeling frameworks and analytical approaches used in this context. Some optimization frameworks used for local energy systems planning include the Distributed Energy Resources Customer Adoption Model (DER-CAM) (Berkeley Lab, 2017), EnergyPLAN (Lund, 2013), and the Dynamic Energy, Emissions, and Cost Optimization (DEECO) model (Bruckner et al., 2003). Local scale studies have been conducted using these and other models. The benefits of using distributed CHP technologies with a microgrid to mitigate carbon emissions in California are demonstrated using DER-CAM in (Siddiqui et al., 2005). Copenhagen's role in achieving a fully renewable energy supply for Denmark by 2050 is investigated using EnergyPLAN in (Mathiesen et al., 2015); synergies are identified between sectors and key urban technologies include building efficiency measures, heat pumps, fuel-efficient district heating power plants, and electrification of the transport sector. A German city, Würzburg, is modeled using DEECO in (Bruckner et al., 1997), which identifies gas cogeneration units as cost optimal compared to a local system relying on oil-based heating and grid electricity. Another study for a local Swedish utility employs a different cost optimization modeling framework, known as MODEST, to identify the least-cost technology mix and operation to supply local heat and electricity demand (Henning et al., 2006). A regional bottom-up optimization model known as the Energy-Technology-Environment Model (ETEM) is also developed and applied to a case study in Geneva in order to investigate the future role of renewable and smart grid technologies in the city (Babonneau et al., 2012). These studies illustrate the breadth of urban energy system models and research questions.

2.2. The city of Basel

The city of Basel is the third largest city in Switzerland, with a population of approximately 195 000 inhabitants (Swiss Federal Office of Statistics, 2016). It is also the second largest urban energy consumer with respect to heat and electricity demand. Basel has a large chemical and pharmaceutical industry, and is the largest exporting district in Switzerland with respect to export value (CHF) and export intensity (export volume in CHF per employee) (Brandes et al., 2009).

Basel is a leading Swiss city with respect to sustainable urban planning. In addition to being a C40 innovator member city, it is also a member of the United Nations-launched Compact of Mayors and the ICLEI Local Governments for Sustainability network (Compact of Mayors, 2016; ICLEI, 2017). Basel has pledged to reduce its CO_2 emissions by 20% in 2020 compared to 2000 levels (Compact of Mayors, 2016).

The municipal government of Basel exercises a high degree of jurisdictional authority over local energy system, infrastructure, and financial planning, as well as waste and water management (C40 Cities, 2017b), placing them in a position to actively shape the city's energy policy and strategy.

Basel is also interesting as an urban case study because it presents a wide range of feasible technology options for evaluation, including natural gas and district heating networks.

2.3. Swiss national energy strategy

National energy strategies for Switzerland are detailed in the publication, “Swiss Energy Perspectives for Switzerland until 2050″ (Kirchner et al., 2012). This study has been commissioned by the Swiss Federal Office of Energy and informs all political energy strategy decisions.

Three main demand scenarios are presented in the Swiss national energy strategy: business-as-usual (BAU), policy measures (POM), and new energy policy (NEP). All three scenarios are driven by the same socio-economic assumptions until 2050. National population growth is assumed to increase to approximately 9 million inhabitants by 2050 (from 7.8 million in 2010), the average real annual GDP growth rate until 2050 is 1.1%, and a social discount rate of 2.5% (per annum) is applied. All scenarios assume the same growth trends in national industrial, construction, commercial and service sectors. Import energy carrier prices also follow similar trends (Densing et al., 2014).

Some of the differences between the scenarios include CO_2 pricing, end-use energy demand technology efficiency improvements until 2050, reductions in heating energy required per square meter due to building efficiency improvements, and vehicle shares and drivetrain efficiencies in the transportation sector. Two scenarios are evaluated in this study, capturing the breadth of scenario policies: BAU and NEP. The scenarios are summarized below. Further details are also provided in (Densing et al., 2014; Kirchner et al., 2012).

2.3.1. Business-as-usual (BAU)

In the business-as-usual scenario, no additional policy measures or acceleration takes place. End-use technology efficiency and heating demand rates improve according to historical trends. The CO_2 tax increases moderately to 56 CHF/t CO_2 in 2050. By 2050, 30% of passenger-kilometers are also met by electric vehicle transport.

2.3.2. New Energy Policy (NEP)

The NEP scenario assumes drastic policy measures compared to BAU. Relatively high efficiency improvements are assumed over time due to strong policy enforcement measures, and the CO_2 tax reaches 137 CHF/t-CO_2 in 2050. The NEP scenario aims to have an emission