CITIES DILEMMA: CUTTING CARBON EMISSIONS OR ALLEVIATING POVERTY ?

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Overview

Facing the emergency of climate change, cities must decarbonize all sectors with important carbon sources by implementing projects either in energy sobriety or low carbon technologies. In the residential heating sector, which represents 15% of domestic emissions in the UK (Rosenow et al, 2020), the main focus is on energy efficiency retrofits and low carbon heating systems. However, some residential heating projects could have adverse effects on consumers and conflict with policies for reducing fuel poverty, which affects 13% of households in the UK (Rosenow et al, 2020). Thus, cities face a complex problem of projects prioritization to maximize the social surplus.

The city of Bristol (UK) has to choose between different residential heating projects: (1) a district heating network implemented in central districts or (2) retrofitting least efficient dwellings. This paper provides an assessment of the cost-effectiveness and the impacts of heating projects using an economic assessment model. The model integrates behavioral and economic processes to reduce the upward bias implied by traditional building-physics based models (Brøgger et al, 2019). Indeed, models such as the Standard Assessment Procedure in the UK (SAP) do not account for rebound effects, hidden costs or consumers heterogeneity, thus increasing the discrepancy between potential and actual energy savings and contributing to the "energy efficiency gap" (Gillingham et al, 2020; Giraudet et al 2021). This paper aims to provide a sound and replicable model to better estimate costs and benefits of heating projects in more realistic assessments.

The model is based on a Cost-Benefit Analysis methodology and consists in an *ex-ante* appraisal of project scenarios against a counterfactual scenario, that extrapolates past trends of energy efficiency retrofits in the city. The model relies on the Energy Performance Certificates data-set and is fed by ressources on projects obtained form an energy service company in Bristol and from the City Council. Impacts on carbon savings, heating costs and comfort gains are estimated at the dwelling level and aggregated with financial costs and revenues in socio-economic Net Present Values (NPVs).

We find that the energy efficiency retrofits program is the most cost-effective, delivering higher benefits per pound invested, while heating networks achieve more carbon emissions and consumers surplus per dwelling but with a higher marginal cost. Besides, energy efficiency retrofits are better at targeting social housing tenures, while heating networks are limited to central district apartments. Finally, integrating behavioral assumptions in the assessment is detrimental to the projects' profitability.

Methods

The model builds a housing stock that elicits households' heating demand and dwellings characteristics in 2021. The model is parameterized with the Energy Performance Certificates data-set, which identifies 130,000 dwellings in Bristol at the address level. EPCs provide current and potential standard heating expenditures for hot water and heating appliances using the SAP methodology. After selecting most recent EPC observations per dwellings, current and potential heating consumptions are estimated by using past energy prices and by correcting the upper bias from standardized consumptions with an econometric approach (Brøgger et al, 2019).

The model updates the building housing stock through 2050, using inputs on project scenarios, energy prices and technological trends. Each year, groups of dwellings are upgraded according to the project scenario, changing their energy consumption and heating characteristics. Updated energy consumptions are estimated using rebound effects and heating demand elasticities conditional on the household tenure type (rental social, rental private, owner-occupied). The simulation is iterated in a Monte-Carlo experiment. The model averages impacts for each project scenario against the counterfactual scenario namely carbon savings, heating costs savings and comfort gains, and returns NPVs by applying different shadow prices of carbon.

Rebound effects and heating demand elasticity estimates are calibrated using the literature (Sorrell et al, 2009). Estimates are taken conditional on the tenure type, since low-income households on average trade-off incremental energy expenditures savings for comfort gains (Aydin et al 2017). Rebound and price elasticities are dissociated to avoid overestimations due to end-users' reaction to both a price change and investment costs and to control for selection biases. Finally, comfort gains are derived from estimates of the "temperature take-back" factor (Sorrell et al, 2009).

Results (preliminary)

District heating networks deliver the most benefits. They cut 3 times more carbon emissions than energy efficiency retrofits, with 0.4 tCO2-eq per household per year, and provide 60% more consumers surplus, with £1,480 per household (in 2021 present value). However, energy efficiency retrofits are more cost-effective, generating 80% additional consumer surplus and cutting 5% additional carbon per pound invested. Energy efficiency projects better target social housing tenures, more likely to be fuel poor, reaching 24% social housing versus 18% for the heating network and deliver the most comfort gains.

The NPV of the projects are positive under the UK's social discount rate at 3.5% and with a social cost of carbon at £106 in 2021 (Nordhaus, 2018). Heating networks NPV is more than two times higher than energy efficiency NPV. This outlines the gap between standard building-physics based assessment models and realistic economic models integrating behavior. Both projects profit from a windfall effect related to energy prices; higher prices trends implying higher consumers' surplus in each scenario.

Conclusions

This paper conducts an *ex-ante* Cost-Benefit Analysis to assess which project is the most cost-effective to achieve the Bristol City Council's desired objectives namely cutting carbon emissions and alleviating fuel poverty. Under realistic assumptions (real energy consumption, actual energy savings, rebound effects) district heating networks and energy efficiency retrofits yield positive NPVs for the city. This result is sensitive to energy price trends, the district heating network could generate more benefits for end-users as gas prices rise (80% of end-users are heated with natural gas).

Each project is more performant in delivering one of the two outcomes. District heating networks generate more carbon savings and consumer surplus while the energy efficiency retrofits program is better to target low-income households and to deliver comfort gains. Bundling the two projects at the dwelling level would be the most attractive option for the city, but there are significant barriers: heating networks being less economically viable in low density districts and involving important works on existing buildings.

The model constructed in this paper is based on open-access and standardized data-set and is calibrated on academic literature, thus it can be easily replicated to other case studies. The model could be improved by incorporating end-users' acutal consumption data, allowing to produce more realistic assessments and to estimate rebound effects and heating elasticites *in-situ.*

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