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Techno-economic and business case assessment of low carbon technologies in distributed multi-energy systems

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HIGHLIGHTS

- LCT and aggregation business case assessment for energy system actors/policymakers.
- Modular, generalizable techno-economic modelling framework.
- Complex physical and economic emergent behaviour captured.
- Energy, emission and operational cash flow metrics.
- Operational cash flows disaggregated by price component/actor.

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ABSTRACT

Increasing focus on energy affordability and environmental impact is drawing interest towards the potential value of low carbon technology (LCT) interventions in buildings and district energy systems. Relevant interventions may include improvements of the insulation levels and installation of low carbon and renewable generation technologies (e.g., combined heat and power, photovoltaics, heat pumps). These LCT interventions for both electricity and heat supply can, in principle, reduce energy costs and CO_2 emissions for final energy consumers. This can be achieved by coupling, and possibly optimising, multiple energy vectors from traditionally independent systems (e.g., electricity, heat and gas). However, this transition to distributed *multi-energy* systems introduces complex physical and commercial interactions between the different energy vectors. Further, these interactions can be fundamentally different at different aggregation levels (e.g., premises, district, and commercial level). This makes the assessment of business cases for LCT interventions in a multi-energy context a grand challenge, and given the potentially disruptive commercial impact of many such novel technologies, such complexity might result in a barrier to their development. In light of this, this paper proposes a techno-economic framework for the assessment of business cases of LCTs, which systematically models the physical and commercial multi-energy flows at the premises, grid connection point, and commercial levels. This is particularly important given the commonly asymmetrical nature of various energy price components, which can have significant effects on the business cases of LCTs and associated actors (e.g., retailers and energy service companies). The proposed framework is demonstrated through a series of case studies that highlight the value of various LCT interventions and of aggregation, in terms of energy, emission and operational cash flow metrics. The relevance and importance of the framework to developing business cases for various energy system actors, including policy makers and regulators, is discussed, with the final aim of facilitating the uptake of low carbon multi-energy technologies.

1. Introduction

The increasing pressures of energy affordability and environmental sustainability are encouraging the emergence of improved energy efficiency and new low carbon technologies (LCTs) [1,2]. These new solutions include insulation improvements and installation of combined heat and power (CHP), photovoltaic (PV) and electric heat pump (EHP) LCTs in buildings, among others. Installation of LCTs can be particularly interesting as they can provide systems with flexibility to couple, and even jointly optimise, different energy vectors (e.g., electricity, heat and gas). This paves the way for a wide roll out of distributed multi-energy systems [3]. In this multi-energy context, traditionally independent systems

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Nomenclature

Acronyms

ASHP	air source heat pump
BSUoS	balancing services use of system
CHP	combined heat and power
COP	coefficient of performance
DHW	domestic hot water
ECO	energy company obligation
EDUoS	electricity distribution use of system
EHP	electric heat pump
ESO	environmental and social obligation
ESCo	energy service company
ETNO	electricity transmission network operator
ETUoS	electricity transmission use of system
FiT	feed-in-tariff
GCP	grid connection point
GDUoS	gas distribution use of system
GTNO	gas transmission network operator
GTUoS	gas transmission use of system
LCI	low carbon incentive
LCT	low carbon technology
PV	photovoltaic
ROC	renewable obligation certificate
RHI	renewable heat incentive
SMI	supply market indicator
SO	system operator
UoS	use of system
VAT	value added tax
WHD	warm homes directive

Notation

Indices

c	commercial entities, 1 to N_c
j	GCPs, 1 to N_j
i	time steps, 1 to N_i
p	premises, 1 to N_p
t	Low carbon electricity generators, $\in T$
u	Low carbon heat generators, $\in U$

Parameters

γ_i^{comm}	commercial level gas prices, £/kW h
γ_i^{GCP}	GCP level gas prices, £/kW h
γ_i^{pre}	premises level gas prices, £/kW h
λ_t	low carbon electricity incentive, £/kW h
μ_u	Low carbon heat incentive, £/kW h
ϕ_i	grid electricity emission rate, $kgCO_2$/kW h
π	gas emission rate, $kgCO_2$/kW h
$\theta_i^{-,comm}$	commercial level electricity import prices, £/kW h
$\theta_i^{+,comm}$	commercial level electricity export prices, £/kW h
$\theta_i^{-,GCP}$	GCP level electricity import prices, £/kW h
$\theta_i^{-,pre}$	premises level electricity import prices, £/kW h

Variables

$e_{i,c}^{-,comm}$	electricity import, commercial level, kW h
$e_{i,c}^{+,comm}$	electricity export, commercial level, kW h
$e_{i,j}^{-,GCP}$	electricity import, GCP level, kW h
$e_{i,p}^{-,pre}$	electricity export, premises level, kW h
$f_{i,p,t}^{pre}$	low carbon electricity generation, kW h
$g_{i,c}^{comm}$	gas import, commercial level, kW h
$g_{i,j}^{GCP}$	gas import, GCP level, kW h
$g_{i,p}^{pre}$	gas import, premises level, kW h
$h_{i,p,u}^{pre}$	low carbon heat generation, kW h

(e.g., electricity, gas and heat) become physically and commercially coupled. The physical and commercial interdependency that this coupling introduces greatly increases the complexity of the techno-economic system. This complexity makes assessment of LCT-related business cases, for various energy actors (e.g., retailers and energy service companies – ESCos) far from trivial. In particular, assessment of the impact of such interventions on operational cash flows is difficult, given the complexity of energy systems. Hence, such assessment may be considered a grand challenge. Even more importantly, as many such novel technologies can be disruptive, in the current commercial environment, for many actors in the value chain, this challenge might result in a barrier to the development of low carbon energy solutions.

Existing literature recognises the multi-vector (or multi-carrier) nature of emerging energy systems. In particular, given the complexity of the interplay between technical and economic factors, emphasis is put on techno-economic models. For example, several techno-economic models have been proposed for the assessment of low carbon interventions. At a disaggregated level, models for insulation upgrades [4–6], placement of heating options (e.g., considering various technologies and emitters [7–9]), and installation of electricity generation and electro-thermal alternatives (e.g., PV and CHP [10–12]) have been proposed. Considering the benefits of aggregation, models of district heating networks [13,14] and private-wire/microgrid arrangements [15–18] have also been advanced. Further, it is becoming more and more evident how there is a need for explicitly modelling physical characteristics of the buildings and heating system elements (e.g. building fabric, hot water storage, heat emitters) [19] as a basis for accurate assessment. Various papers are also addressing the economic and environmental attractiveness of LCT interventions (e.g., [1,20,21]).

While the reviewed works represent an initial step for the assessment of relevant business cases for LCTs, no systematic framework has, so far, been developed for techno-economic analysis of complex distributed multi-energy systems, with different LCTs. Further, given the potential impact of pricing and commercial arrangements (e.g., aggregation [18,22,23]) on business cases, there is not a sufficient level of detail on these operational aspects. Meanwhile, investment related costs are relatively well understood. Therefore, further research is needed on more realistic, representative physical (technical) models, and disaggregated pricing schemes, that capture the operational economic and environmental value of LCTs. Understanding the effects of such business cases in increasingly complex energy systems can be aided by mapping methodologies, which specify the relationships between various parties [24–26]. In this regard, also, further research is required, as existing mapping approaches focus on single energy vectors and lack disaggregation of energy flows by level (e.g., premises, GCP, commercial). This, as described, is critical for the assessment of LCT interventions in the emerging multi-energy context.

In light of the above, this paper proposes a new techno-economic framework for the assessment of business cases, particularly in terms of operational elements, for LCTs and associated network interventions, in economic and environmental terms. The framework is modular, and generalizable to any context. More