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Economic analysis of the routes for fulfilment of net-zero energy buildings (NZEBs) in the UK

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Abstract

This paper evaluated the economic implications of developing net-zero energy buildings (NZEBs) for four types of residential houses (i.e. flat, terraced house, semi-detached house, and detached house), across different locations in the UK. Models specific to different locations and loads were created with varying combinations of renewable energy technologies. Houses were further classified as existing ones and new ones, and the latter had an 55% improvement in energy (heat) efficiency compared to the former. A cost-benefit analysis was conducted for each of the potential NZEB designs. Without energy storage, income from renewable technology in existing households can produce a mean net profit between 5-51% of the overall expenditure for NZEB designs. The results will enable policymakers to make informed decisions for the fulfilment of NZEBs in the UK which can potentially play an important role in mitigating greenhouse gas (GHG) emissions and help the UK achieve its climate change targets.

Keywords: Net Zero Energy Buildings; Electric and Gas Consumption; Renewable Energy; Efficiency; Cost-benefit Analysis;

1. Introduction

Getting to net zero in domestic dwellings is considered to be one of the means to reduce the impacts of climate change. There is an increasing motivation for governments and companies to lead the market in modelling housing designs that can become standardized in the next 30 years. These models will need to discriminate between different regions and dwelling types to allow house designs to fit variable specific requirements and opportunities. By integrating a combination of renewable technologiescertified by the Microgeneration Certification Scheme (MCS), and home efficiency improvements, such as insulating windows, roofs, floors and walls, a net-zero energy building (NZEB) design can be achieved. Existing studies have introduced a consistent definition framework for NZEBs[1]. Some of the major challenges that NZEBs face are related to:

- Technical - Meeting the annual energy consumption with a diverse renewable energy system to ensure security of supply on cloudy, cold or non-windy days.
- Financial – Finding the optimum renewable energies and efficiency improvements that minimise capital costs and maximise income.
- Policy – Ensuring that NZEB designs are in line with government and Ofgem regulations is essential to receive generation and export tariffs.

A variety of economic analysis has been conducted to evaluate the economic feasibility of NZEBs in different countries. For example, targeting at a multi-storey residential property in Denmark, Marszal & Heiselberg [2] found

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that the energy use should be reduced to a minimum to build a cost-effective NZEB, and the district heating grid is more expensive than heat pump use for NZEB. Wang et al. [3] assessed the possibility of NZEB in the UK by specifically looking at the optimal design strategies and feasibility under Cardiff weather conditions. However, this study did not account for the economic feasibility of NZEBs, and the study was only based on Cardiff weather conditions. Realistic energy consumption and production performance of NZEB for other locations throughout the UK are still unknown.

This paper will discuss whether NZEBs are currently a practical housing design option across thirteen cities in the UK. A detailed cost-benefit analysis with respect to different loads per region and dwelling type will be carried out for both existing and new houses. Recommendations will be made to identify what is required to make NZEBs a reality.

2. NZEB design methodology

2.1. Site selection, dwelling types, and renewable energy assignment

Thirteen sites (Glasgow City, East Dunbartonshire, Shetland Islands, Neath Port Talbot, Monmouthshire, Gwynedd, Islington, Hounslow, Sunderland, Reigate and Banstead, East Northamptonshire, and Cotswold) for NZEB designs were identified depending on locations, population densities and electric and gas consumptions to represent a diverse and substantial energy report [4]. . Four major dwelling types (flat, terraced house , semi-detached house, and detached house) were considered [5]..

The electricity and heat consumption data of existing dwellings was estimated based on the report from the Department for Business, Energy & Industrial Strategy as shown in Fig. 1 [6]. To ensure the security of energy supply, the energy consumption data was further increased by a weighting factor (WF) of 1.25 (for Monmouthshire, a WF of 1.6 was used due to its low wind speeds). For a new house that uses new materials with lower U-values, the gas consumption required to heat a house can be reduced by 55% (calculation shown in section 2.5) as shown in Fig. 3.

The strategy for renewable energy (wind turbines, solar PV, solar thermal, air source heat pump (ASHP), ground source heat pump (GSHP), and bioenergy) assignment is as follows: (1) wind turbines and solar PV panels serve as the source of electricity, while solar thermal panels, ASHP and GSHP supply heat; (2) ASHP and GSHP energy productions were firstly considered to compensate for the gas consumption; (3) three different biomass usage (1, 1.5 and 2kgs per day) were evaluated with the number of solar thermal panels used to compensate for the remaining gas consumption; (4) the maximum energy from a wind turbine was identified and the remaining would be balanced by solar PV panels; (5) the surplus electricity sold to the grid. It was determined that 1kg of biomass per day optimized the energy production for new houses minimizes the capital and material costs. Whereas, existing houses required 1.5kgs of biomass material per day.

The renewable energy assignments for existing and new houses are shown in Fig. 2 and Fig. 4, respectively. In Fig. 4, it is evident that by using optimal floor, roof, wall and window insulation this can lead to a large drop in gas consumption, which results in less thermal energy being required for the house. Therefore, as the GSHP has the highest capital costs, it can be removed from the CBA to improve financial results. Fig. 2 and 4 present the varying energy productions for each household and region type. Most systems include roughly the same renewable system, although the Shetland Islands is only powered by electricity. Therefore, there is no requirement for ASHP, GSHP and a biomass boiler in this region. A solar thermal system was provided to produce 1000kWh/year to add some heating diversity.

2.2. Data for analysis

Up-to-date data was collected from national government statistics as listed in Table 1. For parameters of different household types (i.e. flats, terraced house, *etc*), the national average values were used. Regional wind speeds were identified from the national wind speed database [7]. The Met Office provided the yearly sunshine hours and average air temperature (°C) [8]. The average ground temperature was estimated based on the average air temperature. The assumption is that there is a 0.9°C temperature increase at the depth for ground sourced heat pumps [9]. Finally, the yearly global irradiation was estimated using the European Commission Joint Research Centre's solar statistics [10]. The average wind speed is 4.5m/s, the sunshine duration is 1493 hours per year, the yearly global irradiation is 1200kWh/m^2, the average air temperature is 10.6°C and the average ground temperature is 12.4°C.

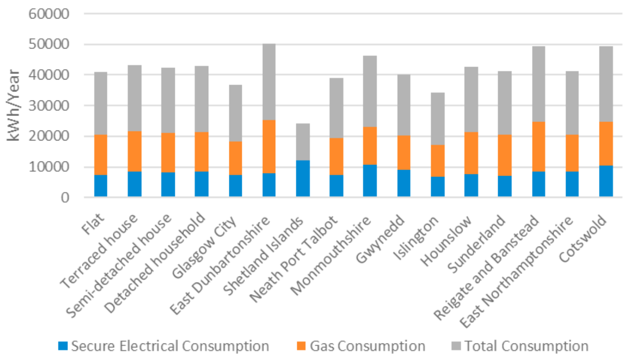

Fig. 1. Electricity and gas consumptions (existing houses).

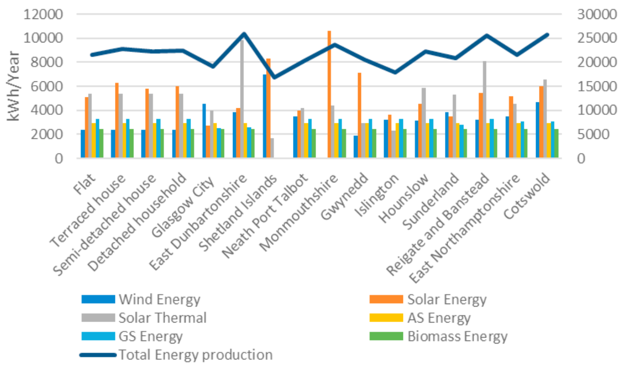

Fig. 2. Renewable energy productions (existing houses).

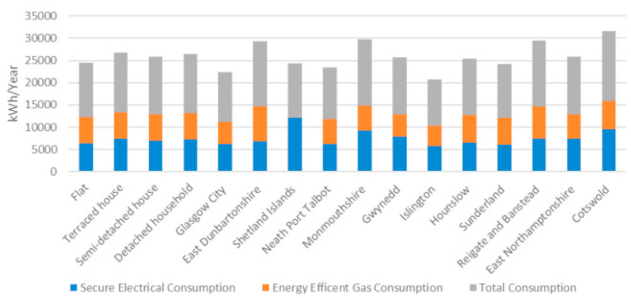

Fig. 3. Electricity and gas consumptions (New houses).

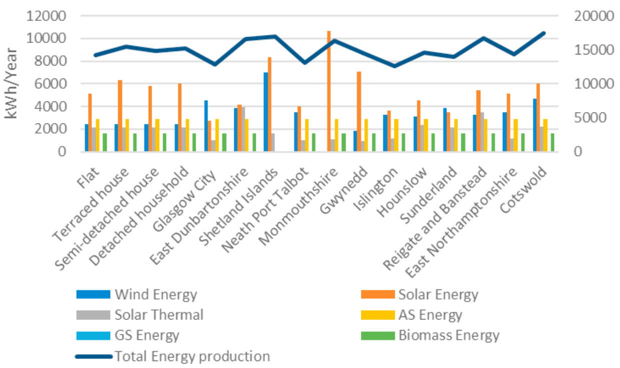

Fig. 4. Renewable energy productions (New houses).

Table 1. Data of wind speeds and sunshine hours per year.

Data Location	Wind speed (m/s)	Sunshine hours per year	Yearly global irradiation (kWh/m^2)	Average air temperature (°C)	Average ground temperature (°C)
Glasgow City	5.6	1203.1	1100	8.85	9.75
East Dunbartonshire	5.2	1248.1	1100	8.95	9.85
Shetland Islands	7.2	1197.7	916	8	8.9
Neath Port Talbot	5	1381.2	1160	11	11.9
Monmouthshire	2.6	1571.2	1220	10.5	11.4
Gwynedd	4.1	1442.9	1090	10.65	11.55
Islington	4.9	1540.4	1300	10.65	11.55
Hounslow	4.8	1653.3	1310	11.05	11.95
Sunderland	5.2	1515	1180	9.4	10.3
Reigate and Banstead	4.9	1591.6	1290	11.25	12.15
East Northamptonshire	5	1498.9	1270	9.8	10.7
Cotswold	5.7	1493.2	1220	9.85	10.75

2.3. Renewable energy output, costs and tariffs

Each renewable energy technology considered has MCS accreditation which makes it eligible for government tariffs. Any surplus electricity will be sold back to the grid at a tariff of 5.24 p/kWh. Generation tariffs are calculated by OFGEM every 3 months depending on market values of the renewable energy.

2.3.1. Wind turbines

The XZERES Skystream 3.7 was selected for micro-wind generation [11]. The 2.1 kW rated wind turbine cost is approximately £4500 [12] and there is presently a generation tariff of 8.24 p/kWh [13]. The monthly energy output (P) depends on the wind speed (V_w) as shown in Fig. 5.

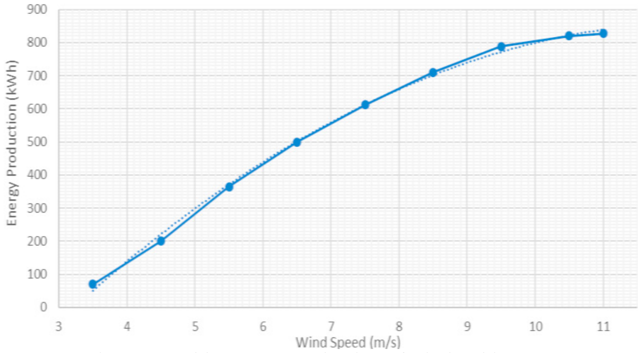

Fig. 5. Monthly energy production of wind turbine [11].

2.3.2. Solar PV

The SRP-6MB solar panel was selected for the analysis [14]. For a solar PV between 10 kW to 50 kW, it would have a generation tariff of 4.03 p/kWh [13]. The cost of the system was scaled up based on the size in kW [15]. The energy output was calculated based on the solar panel area, rated power, sunshine hours and the system efficiency.

$$P = R_p \times T_s \times \eta_s \times A_p \tag{1}$$

where R_p is the rated power, T_s is the sunshine hours per year, η_s is the efficiency of solar PV, and A_p is the area of solar PV panel.

2.3.3. Solar thermal

The cost of the system was scaled up based on the size in m^2 and the generation tariff is 20.66 p/kWh [13]. The energy output was calculated based on the collector area (A_c) and efficiency (η_c), yearly irradiation (I_y) and system efficiency (η_s).

$$P = \frac{A_c}{I_y \eta_c \eta_s} \tag{2}$$

2.3.4. ASHP

The cost of a heat pump was quoted at £6000 [16] and there is a generation tariff of 10.49 p/kWh [13].

2.3.5. GSHP

The cost of a heat pump is approximately £14000 [16] and the generation tariff is currently at 20.46 p/kWh [13].

2.3.6. Biomass

The estimated cost of a biomass boiler is £4218 and the pellets are approximately £255 per tonne [16]. The generation tariff is 6.74 p/kWh [13].

2.4. Energy bill savings

The annual energy bill savings were also included in the analysis. The average electricity price, 14.4 p/kWh, and gas price, 0.0364 p/kWh, were multiplied by the estimated consumptions [17] as shown in Fig. 1 and 3.

2.5. Efficiency improvements

This study considers a scenario of new houses with reduced dwelling U-values (W/m^2/K) by using improved methods of insulation in walls, floors, roofs and windows. By using MacKay's heating efficiency analysis, it was estimated that gas consumption can be reduced by approximately 55% [18] as shown in Fig. 3.

2.6. Cost-benefit analysis

The purpose of the cost-benefit analysis (CBA) is to provide decision makers with a framework for assessing the economic desirability investing in renewable technology and efficiency improvements. Included in the cost benefit analysis is net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR) and cash flow balance (CFB) [19]. NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time.

$$NPV = \sum_{t}^{LT} \frac{C_{it}}{(1+r)^t} - C_0 \tag{3}$$

where C_{it} is the net cash inflow during a year t; C_o is the total initial investment (e.g., capital costs); LT denotes the life time of the renewable technologies, which ranges from 15 years for an ASHP to 25 years for a wind turbine; r = 0.07 is the discount rate. BCR shows the relationship between the costs and benefits of the NZEB, in economic terms.

$$BCR = NPV \Bigg/ \left(\sum_{t}^{LT} \frac{C_{et}}{(1+r)^t} + C_0 \right) \tag{4}$$

where C_{et} is the expenditure cost (e.g., maintenance costs) during a year t. IRR is a discount rate that produces a zero NPV. CFB shows the net cash income and costs without including any discount rates, to indicate whether it is theoretically possible to achieve a profit.

3. Results and discussion

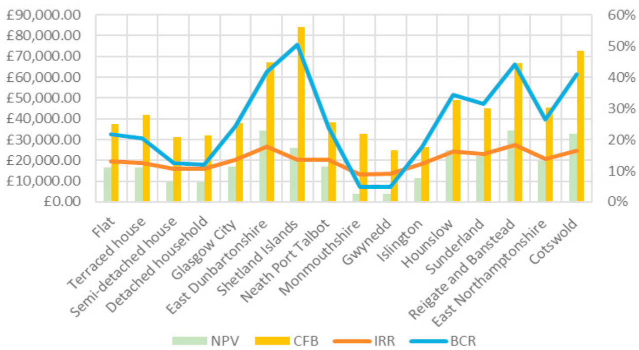

Fig. 6. CBA of existing houses across different regions.

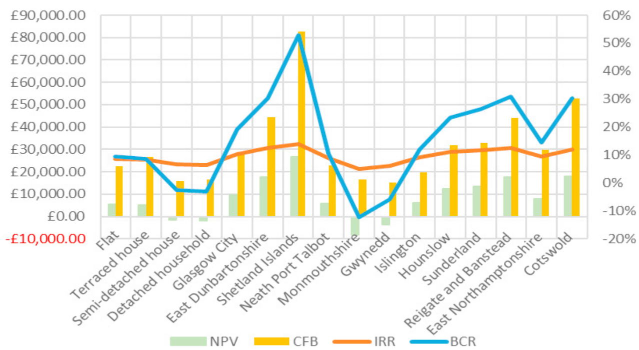

Fig. 7. CBA of new houses across different regions.

The results of CBA on the existing and new house designs across different regions are shown in Fig. 6 and 7. A total of 28 out of 32 NPV calculations produced a net profit, for a discount rate of 0.07 [20]. The CFB results show that all the cases are theoretically profitable. The IRRs vary between 5-18%, although it is the existing houses that generally have higher IRRs. The BCR results show that the income from the use of renewable energy technology for NZEB designs in existing households can produce a mean net profit between 5-51% of the overall expenditure. Whereas, new houses have a BCR that ranges from -12-53%. The results indicate that investing in a new energy efficient household is financially worse off in the long run. This is due to the fact that the capital costs generally remain the same for most regions whereas the generation income is far lower. The Shetland Islands show the most promising CBA because the island houses are powered by electricity only. To match the electricity demand, the solar panel area was increased, which increases the generation tariff income. Additionally, the capital costs of solar thermal GSHP and ASHP were excluded.

4. Conclusion

This paper studied the economic feasibility of the household and regional variations of NZEBs throughout the UK. The technical challenge of supplying sufficient renewable energies to homes to provide all year-round energy can be fulfilled. The NZEB design could potentially be economically viable for most of the cases if the opportunities benefit from bill saving was considered while the expense in energy storage was disregarded. The cost of energy storage is still a critical player for the practical implementation of distributed renewable energy systems. Future work should include the costs and implications of energy storage, and account for the uncertainty and variability in the cost and benefit data. It is also critical to understand how renewable energy generation at different times through the day matches the variation in the energy demand.

Acknowledgements

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