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THE PROFITABILITY OF VARIOUS ENERGY SUPPLY SYSTEMS CONSIDERING VARIATIONS IN FUTURE CLIMATE CONDITIONS

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ABSTRACT

Ambitious targets were set in Sweden to increase the share of renewable energy resources and reduce greenhouse gas emissions. Renovating old detached houses can assist in achieving the abovementioned targets, since they make up a great share of the final energy consumption and carbon dioxide emissions in Sweden. Although, several attempts were taken to improve the energy performance of the detached houses, the implementation of energy efficient renovation is yet low due to mainly high investment cost. Former studies evaluated the cost effectiveness of various energy efficient renovations in renovating detached houses in Sweden, but they provided no information how possible climate futures affect the determination and adoption of energy efficiency policies, such as monetary instruments. Accordingly, this study considered three distinct energy renovation packages and analyzed the subsidies required for implementing renovation packages for given interest rates and lifetimes. Furthermore, three different climate scenarios were considered to analyze the effect of possible climate futures on subsidies required. The analyses of results show that increasing the lifetime have greater impact on required subsidies than increasing the interest rate. Furthermore, the results show that variation in future climate conditions changes the required subsidies when implementing energy efficiency renovations. Results can be used as an aid when adopting energy efficiency policies.

Keywords: energy renovation, renovation policy, possible climate futures, subsidies

1. INTRODUCTION

Sweden passed legislation to attain 100% renewable energy production along with net zero emission of greenhouse gases targets by 2040 and 2045 respectively [1]. The targets were set as a response to international agreements in mitigating environmental impacts [2]. To fulfill the targets, drastic actions should be taken in form of adoption and mitigation policies in several sectors [3]. Building sector play a fundamental role in achieving the national targets since they make up about 24% of the final energy consumption [4] and 8.5% of the total carbon dioxide emissions[1] [5], from which 40% comes from detached houses [4]. The majority of these houses were built between 1960 to 1980, accordingly they have poor energy performance due to technical deteriorations in heating, ventilation and air conditioning systems as they approach to the end of their expected lifetime. Furthermore, they were built before strict energy codes came into play in Sweden, therefore are in need for deep energy renovations to conform current energy codes in Sweden [6]. However, the implementation of deep renovations for improving the energy performance of detached houses is rather low due to existence of multiple barriers [7-9]. But high investments costs were identified as the most common barrier in the implementation of deep renovation in detached houses in Sweden [10]. Multiple studies were therefore

[1] The building sector was responsible for 21% of the total carbon dioxide emissions in 2016, from which 40% released during operations phase [5].

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conducted to discuss the cost-effectiveness of different energy efficiency measures in renovating detached houses [11-14]. However, former studies have mainly excluded the contribution of possible climate futures on total energy demand and cost-effectiveness of energy renovation measures. According to Damm, Köberl [3], a +2 ℃ increase in global temperature can cause a significant reduction in electricity need for supporting heating demand in Sweden, while it has a negligible effect on cooling demand. Any such observation plays a significant role in the determination and adoption of energy efficiency policies, such as monetary instruments.

This study analyzes three distinct energy renovation packages for a detached house in Sweden and quantifies subsides required when implementing renovation packages for interest rates of 1%, 3%, and 5% also lifetimes of 30 (2020-2050) and 60 years (2020-2080). The required subsides were calculated for three climate scenarios. In first climate scenario, it was assumed that the current climate conditions remain unchanged until 2080. In second climate scenario, it was presumed that climate conditions are changed until 2050 but they will remain stable until 2080. Finally, in third climate scenario, it was assumed that climate conditions are changed until 2080.

2. METHODS

The detached house was located in Växjö municipality, Sweden. The total heated area was about 140 m², divided over two floors above the ground. The thermal specification of the detached house and its heating, cooling and air conditioning (HVAC) system follow the national building codes in 1979 (Table 1). The energy performance of the detached house was evaluated using EnergyPlus simulation tool (8.5.0). The energy supply system was an electric boiler, connected to water-based radiators and underfloor heating system.

Table 1. The characteristics of the detached house

U-value of building envelopes	
External walls	0.25 (W/m². K)
Roof	0.41 (W/m². K)
Floor	0.29 (W/m². K)
Windows	1 (W/m². K)
Airtightness at a pressure of ±50 Pa	1.6 (l/s.m²)
The temperature setpoint of the heat distribution system (water-based radiators)	60 ºC
The occupancy schedule	16h during working days and 24h during weekends
Operative temperature	18º -22º C
Air flow rate	±0.35 l/m²
The efficiency of the supply fan	70%
The efficiency of the heat recovery system	75%

In total, three packages were specified when renovating the detached house (Table 2).

Table 2. Renovation packages

Packages	Description
1	Connecting the detached house to biomass-based district heating system
2	Installing a ground source heat pump
3	Installing a ground source heat pump along with photovoltaic panels (GSHP-PV)

Additional EnergyPlus weather data files for 2050 and 2080 were generated using CCWorldGen tool [15]. The current EnergyPlus weather data file was used when evaluating the effect of first climate scenario, while weather data file for 2050 and 2080 were used when analyzing the effect of second and third climate scenarios on total energy consumption respectively. The CCWorldGen tool allows one to follow Special Report of Emissions Scenarios (SRESs) and generate climate change weather data file for world-wide locations [16]. The SRESs were presented by international Panel on Climate Change (IPCC) [2] based on socio-economic futures [16]. Each scenario includes four families, known as A1, A2, B1 and B2. Family 1 relates to a homogenous future with strong globalization, while family 2 refers to heterogeneous future with a strong regionalization [18]. Table 3 shows the predicted temperature change for each family [18]. This study uses family A2 when generating weather data files for 2050 and 2080, because family A2 predicts more fragmented changes with a high level of energy use when compared with other families [16, 18].

Table 3. SRES families and future temperature

Families	Future temperature change by 2100
A1	1.4 C°-6.4 C°
A2	2.0 C°-5.4 C°
B1	1.1 C°-2.9 C°
B2	1.4 C°-3.8 C°

Equation 1,2 and 3 were used when calculating subsides required for each renovation packages [19].

[2] IPCC presented two series of scenarios to predict and describe various climate futures: The Special Report of Emissions Scenarios (SRES) and the Representative Concentration Pathway (RCP). Although former studies analysed the effect of the scenarios on future energy consumption, van Vuuren, Edmonds [17] argued that RCPs were developed by research communities, rather than IPCC. Accordingly, there is certain concerns about reliability of RCPs.

Subsides explain monetary instruments, in which the cost for performing energy renovations with a given interest rate is entirely repaid.

$$\text{NPV} = \sum_{t=0}^{n} (D'_t) * \frac{1}{(1+r)^t} - (I+U) \qquad \text{Eq. 1}$$

$$D'_t = (E_0 - E_t) * \alpha(1+\beta)^t \qquad \text{Eq. 2}$$

$$I = I_0 - S \qquad \text{Eq. 3}$$

Where;
NPV is the net present value during lifetime of n year;
D'_t is annual energy saving cost;
E_0 is the initial total energy consumption before renovations;
E_t is the secondary total energy consumption after renovations;
R is interest rate;
t is lifetime of n years;
α is energy price per kwh/m²;
β is inflation in energy price (%);
I_0 is the investment cost;
U is the maintenance cost;
S is subsidies

The investment costs of the renovation packages and their respective maintenance, installation and labor costs is presented in table 3. In calculating subsides, an inflation rate of 1% was considered. The energy prices for heating and electricity were set to 0.76 SEK/kWh and 1.38 SEK/kWh respectively [20]. The lifetime of the district heating system, ground source heat pump (GSGP) and PV system were assumed to be 25, 15 [21], and 20 years [22]. In calculating subsidies, the supply systems were replaced when they approached to the end of their lifetime.

Table 3. Investment and maintenance costs of renovation packages

Packages	Investment	Maintenance	Installation and labor
1*[23]	40 000 (SEK)	750 (SEK)/Y	35 000 (SEK)
2[21]	6000 (SEK/kW)	150 (SEK/ kW.Y)	24000(SEK/kW)
3*[21, 22]	PV:19 000 (SEK/kW) GSHP:6000 (SEK/kW)	PV:342 (SEK/ kW.Y) GSHP:150 (SEK/ kW.Y)	PV:3800 (SEK/kW) GSHP:24 000 (SEK/kW)

*Including 30% tax deduction

The calculations of subsidies started by evaluating the yearly effect of each climate scenario on initial and secondary total energy consumptions (E_0 and E_t in equation 2). Because, weather data files for 2020, 2050, and 2080 allowed calculating total energy consumptions for year 2020, 2050, and 2080 respectively. While the initial or secondary total energy consumptions would be gradually changed from 2020 to 2050 and 2020 to 2080, resulting to distinct yearly total energy consumptions. This process allowed calculating the initial and secondary total energy consumption for each year (E_0 and E_t) and quantifying the annual energy saving cost for each year (D'_t in equation 2).

3. RESULTS AND DISCUSSIONS

The current total energy consumption of the detached house with an electrical boiler was about 109 kWh/m², which is 2% less than actual energy consumption in 2018. The space heating, and space cooling shared about 58% and 8% of the initial total energy consumption, while the ventilation system and domestic hot water (DHW) were responsible for about 13% and 21% of the initial total energy consumption respectively.

Figure 1 shows the current and future variations in total energy consumption among renovation packages. The analyses of results show that the electrical boiler and the district heating system had an identical energy performance, however it replaced the heating energy source from electricity to district heating. While the GSHP and GSHP-PV systems reduced the total energy consumption by 61.5% and 99.8%. The effectiveness of GSHP system in reducing the total energy consumption in 2050 and 2080 was lowered to 59% and 57% respectively. Because changes in the future climates reduced the heating demands, while it added on cooling demands. In contrast, the effectiveness of GSHP-PV system in reducing the total energy consumption in 2050 and 2080 was increased to 100%. This occurred due to increase in both solar radiation and temperature in future, which augmented the amount of the energy generated by PV system.

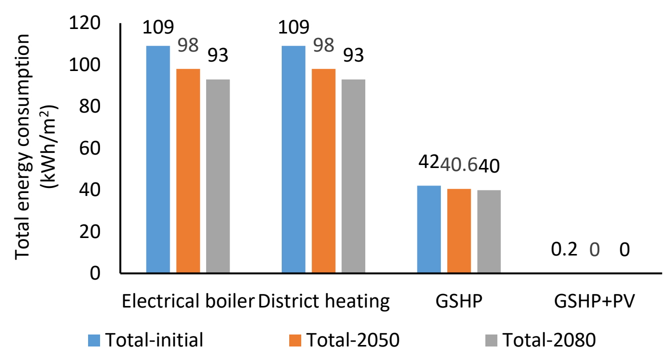

Fig 1. Variation in total energy consumption

Figure 2 shows subsidies required when implementing the renovation packages. The analyses of results show that second and third climate scenarios increased the subsidies, because these climate scenarios cut the total energy consumption, thereby they reduced the cost for energy saved. Accordingly, the second and third climate scenarios exacerbate the negative impact of investment costs on profitability of renovation packages, leading to an increase in subsidies required.

With a lifetime of 30 years and an interest rate of 1%, the costs for installing district heating system and GSHP were entirely repaid. This occurred due to low investment costs of district heating and GSHP systems, when compared with GSHP-PV system. With a lifetime of 30 years and an interest rate of 3%, yet no subsidies were required for installing district heating only when the first climate scenario was applied. But, the second and third climate scenario depreciated the saved cost obtained through installing the district heating system. Although, the district heating system provided no reduction in total energy consumption, it reduced the energy cost for heating by 0.62 (SEK/m^2). Furthermore, with a lifetime of 30 years and an interest rate of 3%, yet no subsidies were required for installing GSHP, because this supply system reduced the total energy consumption effectively, while had relatively low investment cost. With a lifetime of 30 years and interest rate of 3%, the GSHP-PV system had the highest required subsidies. Although, this supply system reduced the total energy consumption effectively, its high investment cost outweighed the cost for saved energy. Increasing the interest rate to 5% reduced the financial gain yielded by implementing the renovation packages, thereby it increased the required subsidies for all packages. In addition, the analyses of results show that with a lifetime of 30 years and interest rates of 3%, and 5%, the GSHP was most financial rewarding renovation package, due to its performance in reducing the total energy consumption and its relatively low investment cost.

With a lifetime of 60 years and an interest rate of 1%, no subsidies were required for installing the district heating and GSHP systems. The GSHP-PV system required no subsidies when the first climate scenario was applied. However, the second and third climate scenarios added on subsidies required for installing GSHP-PV system. Because, these scenarios reduced the cost for saved energy, thereby they diminished the financial gain obtained by installing GSHP-PV system. When the interest rate was increased to 3%, no subsidies required for installing the district heating system only when the first climate scenario was applied. This occurred due to low investment cost of the district heating system. However, increasing the interest rate to 5% strongly depreciated the cost for saved energy and increased the required subsidies for implementing the renovation packages. Furthermore, the analyses of results show that when lifetime is 60 years and interest rates is 3% or 5%, district heating system required lowest subsidies, due to its low investment cost.

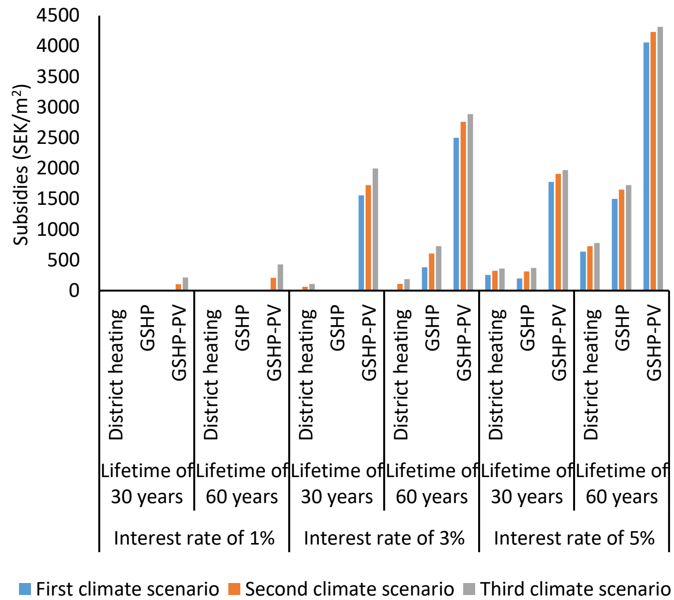

Fig 2. Subsidies required for implementing renovation packages

Figure 3 shows the differences in required subsides when changing the interest rates for first climate scenario. Further analyses of results show that changing the lifetime from 30 years to 60 years had greater impact of required subsides than changing interest rates. For instance, when interest rate was changed from 1% to 5%, the differences in subsides required for installing district heating, GSHP, and GSHP-PV systems for a lifetime of 30 years were 31%, 17% and 44% smaller than differences in subsides for a lifetime of 60 years.

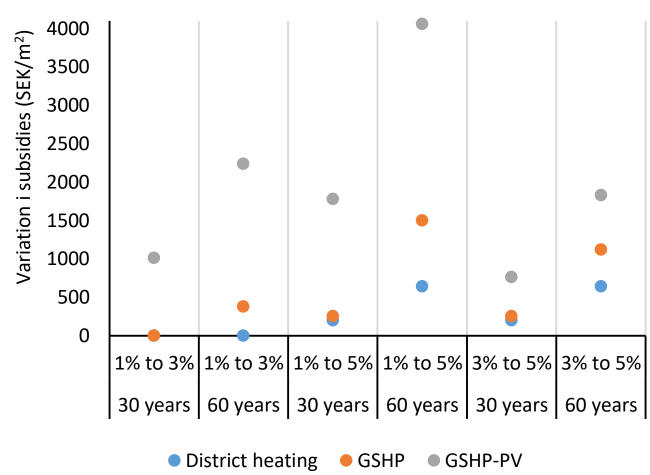

Figure 3. differences in required subsides

3.1 Conclusions

The Swedish government set ambitious targets, which bind the country to achieve 100% renewable energy production and net zero emission of greenhouse gases by 2040 and 2045. At this point, building sector is responsible for about 24% of the total energy consumption and 8.5% of the total carbon dioxide emissions in Sweden, from which 40% comes from detached houses. The majority of the detached houses require energy efficient renovations to satisfy current national energy codes. Although, former studies analyzed the cost effectiveness of various renovation packages, they provided no information how possible climate futures can affect subsidies required for implementing the packages. Accordingly, this study considered three distinct energy renovation packages for the replacement of the existing supply system in detached house in Sweden and analyzed the subsidies required for implementing renovation packages with interest rates of 1%, 3%, and 5% along with lifetimes of 30 and 60 years. The first renovation packages included installation of a district heating system, while the second and third packages comprised installation of a ground source heat pump and mounting integrated ground source heat pump with photovoltaic systems. Three climate scenarios were set to analyze the effect of possible climate futures on subsidies required. The first climate scenario assumed that the current climate conditions remain unchanged until 2080. The second climate scenario presumed that climate conditions are changed until 2050 but they remain stable until 2080, while third climate scenario assumed that climate conditions are changed until 2080.

The analyses of results show that second and third climate scenarios increased the subsidies required when implementing the renovation packages. Because, the abovementioned climate scenarios decreased the total energy consumption, thereby depreciated the cost for saved energy.

Furthermore, the analyses of results show that changing lifetime from 30 to 60 years had greater impact on required subsidies than increasing the interest rate. These results are in conformity with results presented by Jalilzadehazhari and Mahapatra [24] as increasing lifetime has greater effect on required subsides than changing interest rates.

The presented results in this study can be used as an aid when adopting energy efficiency policies in Sweden. In future study, the renovation packages will be expanded to include replacement of windows and insulation layers of building envelopes. Furthermore, the implication of variations in energy prices on required subsidies will be also analyzed.

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