Energy efficiency in the commercial rented sector and considerations on the rebound effect after PV system installation in a shopping center in Spain

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Main Topic and subtopic - Energy Efficiency – Energy Efficiency Gap

1. Background and motivation

Across Europe, buildings account for 40% of energy consumption and 36% of carbon emissions. It is estimated that 75% of buildings in the European Union (EU) are inefficient, yet only 1% of buildings are renovated each year [1]. As part of the EU H2020 funded SmartSPIN (Smart Energy Services to solve the split incentive problem in the commercial rented sector) project, a novel business model to support efficiency measures in rented premises, is being developed and evaluated. The business model will provide an equitable, transparent model for splitting the energy savings and the costs of energy efficiency measures and services between landlords, tenants and energy efficiency service providers. The business model aims to reduce the split incentive issue, which occurs when the benefits of investing in energy efficiency do not accrue to the actor who pays for the energy efficiency measures. The split incentive issue is one of the major market barriers to energy efficient building renovations across rented buildings in Europe and could result in exacerbating the severe energy efficiency gap in the rented sector [2]. Energy efficiency measures are being installed at demonstration sites of SmartSPIN. These measures include a PV-system which has been installed at La Gavia shopping centre, Madrid. This paper aims to review the proposed business model and energy efficiency service and to generate awareness among the stakeholders regarding the rebound effect associated with the adoption of PV system in commercial buildings, analysing data from the PV-system installed at La Gavia shopping centre. Indeed, awareness regarding rebound effect may influence the agreements between the parties in an energy performance contract because it determines a reduction in expected energy savings that is caused by a behavioural change of the energy consumers. Finally, the paper will briefly review other energy efficiency measures relevant with the commercial rented sector.

2. Methodology

SmartSPIN is developing a novel energy efficiency service and demonstrating it in two office buildings in Ireland and Greece as well as in two shopping centres in Spain [3]. The service is illustrated schematically in Figure 1. An Energy Service Company (energy efficiency provider) is in charge of installing and maintaining energy efficiency measures in a commercial rented building and provides guaranteed savings to their clients (Building owner and tenants). The service relies on an innovative type of energy performance contract where both building owner and tenants are listed as clients of the ESCO. In addition to clauses included in all the energy performance contracts, the SmartSPIN contract includes clauses that allow to overcome the split incentive and share the value of the energy savings between the parties in a fair manner [4]. The tenants will enjoy reduced energy bills and will pay a fee for the energy efficiency service to the ESCO. The reward that the ESCO provides to the building owner stimulate investments in energy efficiency and contributes to reduce the split incentive barrier. The investment required for the purchase of energy efficiency measures can be performed either by ESCO or building owner.

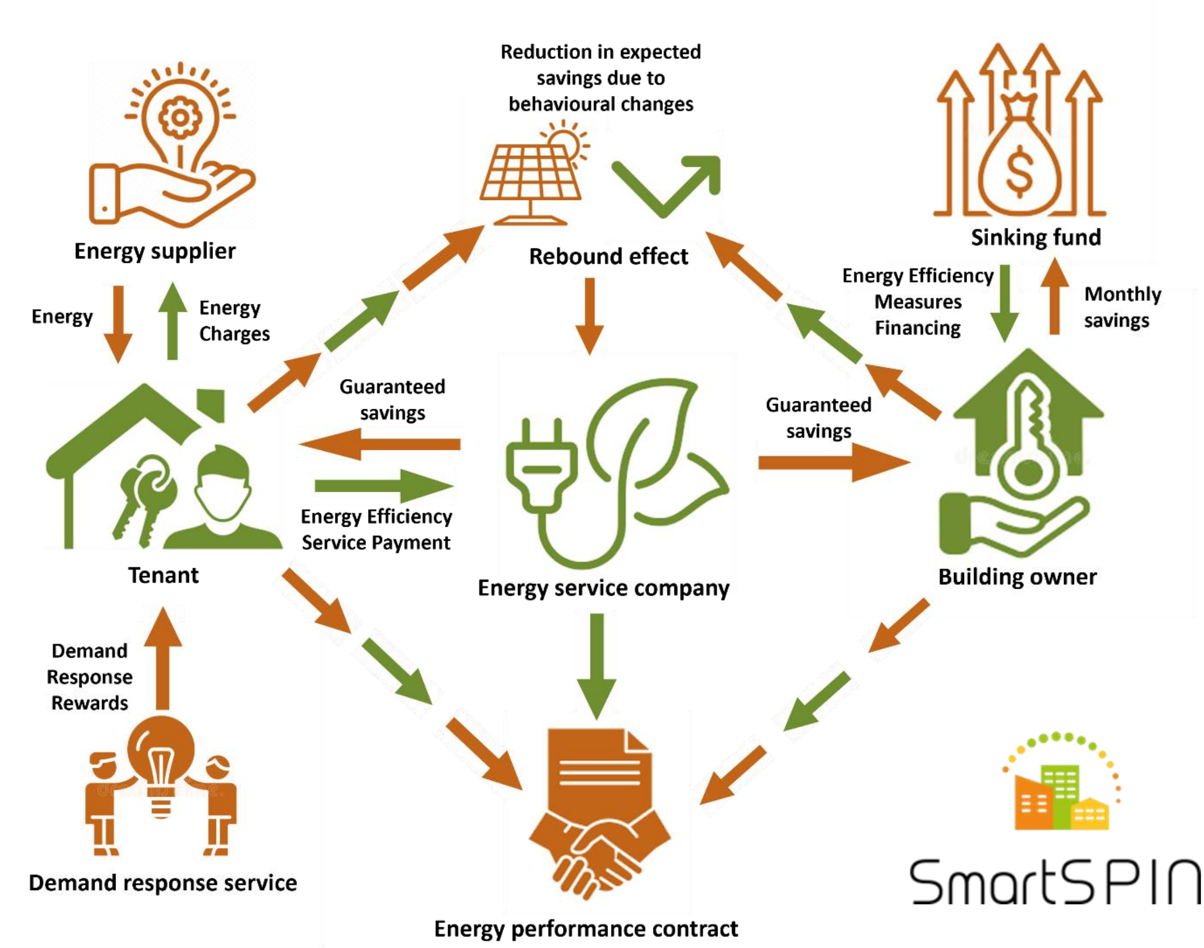


Figure 1 – SmartSPIN service and business model

In Figure 1 it is highlighted that the rebound effect may reduce the expected energy savings, therefore the decision-makers should be aware of it.

Lu, Zhang and Chen proposed a calculation methodology and an optimization model to determine the amount of energy savings obtained by an Energy Saving Performance Contract that a building owner should share with the renters (tenants) in order to maximize the Net Present Value for himself while guaranteeing a positive Net Present Value for Energy Service Company [5]. The approach proposed in [5] may be extended by estimating the maximum value of rebound effect using real data, e.g., considering a PV system along with measured data for the PV-generation. The rebound effect is modelled as a multiplying factor $0 < Re \leq 1$ that is applied to the total energy cost savings generated by the energy efficiency measures, as shown in (1). Figure 2 shows the variation of Re with θ and Φ. We assume that $\rho = -20$ (risk attitude of renters) in (1).

$$b = \frac{\Phi}{1 - e^{-100/\rho}} \qquad a = 1 - b \qquad Re = a + b \cdot e^{-(200 \cdot \theta - 100)/\rho} \qquad (1)$$

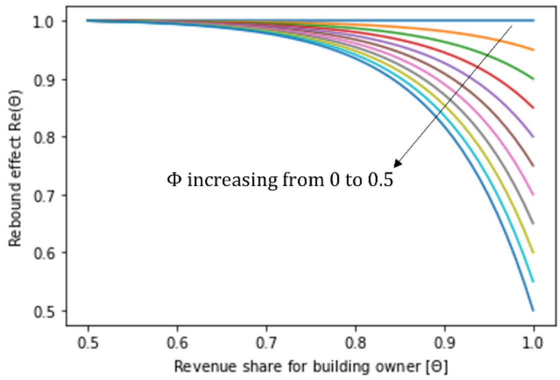


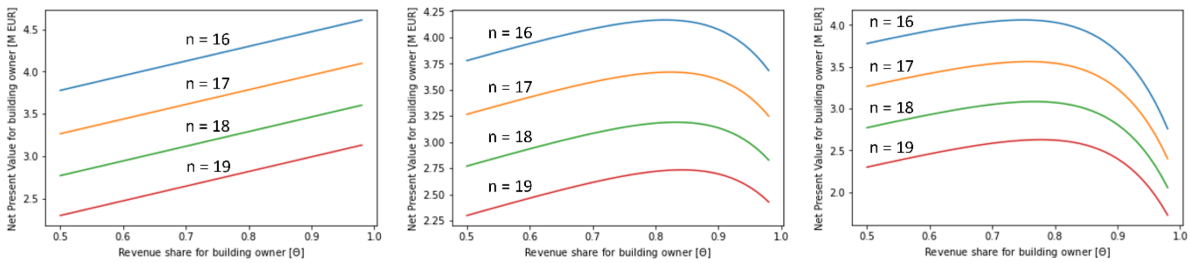
Figure 2 – Rebound effect multiplication factor.

3. Main Results and Implications

We have studied the Net Present Value for the building owner for different values of the rebound effect coefficient Φ in (1) and for different values of revenue share θ for the building owner, considering different contract durations n, from 16 to 19 years (results in Figure 3).

The following parameters were used for the simulations (for their meaning refer to [5]):

1 Volatility of the O&M cost coefficient: σ_H = 0.25
2 Volatility of the energy saving amount coefficient: σ_K = 0.01
3 Energy price drift effect: α_E = 0.0523
4 Energy price volatility effect: σ_E = 0.0856
5 O&M trend index: δ = 1.025
6 Initial value of the O&M cost coefficient: H_0 = 0.0036
7 Initial value of the energy saving amount coefficient: K_0 = 0.3
8 Initial value of the energy price: PE_0 = 0.24
9 Economic lifetime of the energy efficiency system: **N** = 25
10 Capital cost of the energy efficiency investment: I_C = 6170000 (*invested by ESCO*)
11 Annual energy cost savings guarantee: **G** = 431900
12 Owners' expected revenue share within the guarantee: α = 1
13 Owners' excess revenue share beyond the guarantee: β = 0.2
14 Owners' expected rate of return: r_0 = 0.031
15 Renters' expected rate of return: r_R= 0.031
16 ESCOs' expected rate of return: r_E = 0.06
17 Owners' expected revenue share with renters: θ = variable
18 Maximum renters' rebound effect: Φ = variable
19 Risk attitude of renters: ρ = −20



Φ = 0 Φ = 0.2 Φ = 0.4

Figure 3 – Net Present Value for Building Owner considering different levels of rebound effect.

It has been found that the revenue share of building owner that maximizes building owner's NPV and the corresponding NPV strongly depend on the rebound effect coefficient Φ (Figure 4). If the rebound effect increases, the optimal revenue share for the building owner may decrease, because the rebound effect might have to be reduced to improve the NPV for the building owner (see also Figure 2).

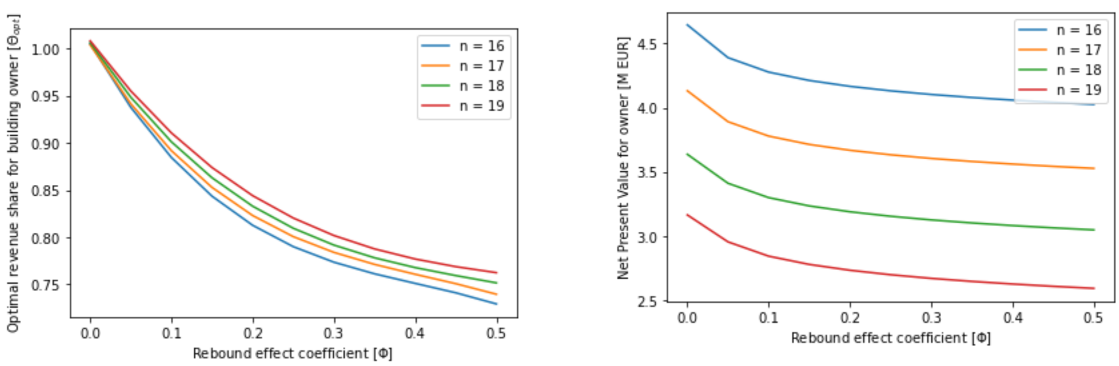


Figure 4 – Optimal revenue share for building owner (left hand side) and Net Present Value (right hand side) as function of rebound effect.

Aydın et al. analysed the rebound effect associated with PV-generation in the residential sector [6]. The energy consumers change their behaviour and after installation of a PV-system will tend to shift their energy consumption toward the hours where energy generation is higher and overall to consume even more energy as they know that PV generation will come at nearly zero cost for them. The instantaneous relationship between electricity consumption and solar electricity generation may be obtained by plotting on a cartesian graph the former (dependent variable) against the latter (independent variable). Such increment represents the rebound effect if the sunshine only affects shopping centre's electricity consumption through the response to solar electricity production [7].

A PV-system was installed in La Gavia shopping centre, located in Ensanche de Vallecas district, 11 km from the city centre of Madrid. La Gavia includes 175 retail shops. Data collection started on September 1st, 2022, with hourly resolution. Energy consumption data collected from 01/09/2022 01:00 to 01/07/2023 00:00 (time period 2) have been compared against data collected from 01/09/2021 01:00 to 01/07/2022 00:00 (time period 1). In time period 1, the total consumption was 2.28 GWh whereas in time period 2 it was 2.07 GWh. In time period 2, PV generated 0.46 GWh, about 22% of the total consumption. Figure 5 shows the total energy consumption of the shopping centre versus the PV generation. Energy consumption increases as the PV generation increases. A regression analysis shows that the total energy consumption increases on average of 0.6 kW when the PV generation increases of 1 kW. Moreover, the analysis of the relationship between total energy consumption and energy consumption from PV consumption has been conducted for different individually metered energy clusters (total energy consumption of all the clusters, mall, first HVAC plant and second HVAC plant) highlighting different relationships between the two variables. The relationship between total energy consumption and consumption from PV might also involve a change in timing of consumption. Therefore, the lagged PV electricity generation was introduced in the regression model of the total energy consumption [6]:

$$E_{C,Tot}^{(t)} = 214.2001 - 1.2093 \cdot E_{PV,Tot}^{(t-4)} - 0.6694 \cdot E_{PV,Tot}^{(t-3)} + 0.3958 \cdot E_{PV,Tot}^{(t-2)} - 1.0070 \cdot E_{PV,Tot}^{(t-1)} + 1.1766 \cdot E_{PV,Tot}^{(t)} \quad (2)$$

The model (2) is slightly more accurate than the instantaneous model with a root mean squared error of 112.1167 versus 122.8736. The estimated coefficients in (2) are statistically significant because the p-values associated with them are very close to zero. The model (2) highlights that an energy consumption shifting within four hours is likely to happen when PV consumption increases. The number of lags in (2) has been chosen considering that regression coefficients with a p-value greater than 0.05 are not statistically significant and must be rejected [6]. In fact, adding one more lagged variable would lead to some p-values greater than 0.05. The requirement of statistical significance for the regression coefficients limits the number of lagged variables that can be included in the model and therefore the amount of energy consumption shifting that can be explained by using the linear regression model. It is worth noting that the rebound effect is likely to be overestimated for the Heating Ventilation and Air Conditioning (HVAC) plants 1 and 2 because, beside rebound effect, higher sunshine will determine a higher cooling load and therefore higher HVAC consumption. Submetering allowed to determine rebound effect for the Mall only (excluding HVAC plants).

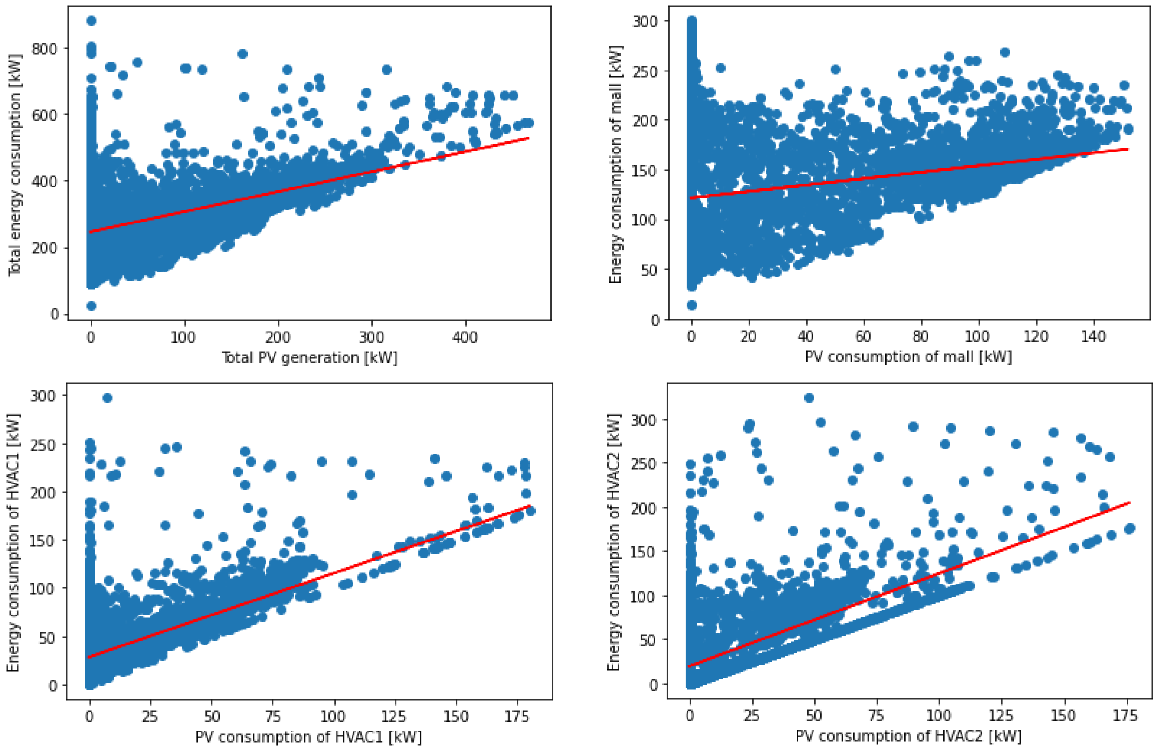


Figure 5 - Energy consumption of La Gavia shopping center versus on-site PV generation

Energy consumption cluster	**Estimated rebound effect**
Total energy consumption	60.25%
Mall	32.5 %
HVAC 1	*87.11* %
HVAC 2	*105.01* %

Table 1 – Estimation of rebound effect for different energy clusters of La Gavia shopping centre (instantaneous relationship).

4. Other energy efficiency measures

Analysing the published literature, a set of energy efficiency measures along with their potential energy savings have been identified (Table 2) [8-9]. These measures may be included in the package that energy service provider will install to deploy the service in Fig. 1.

Energy management measure	**Envisaged energy savings**	**Energy management measure**	**Envisaged energy savings**
Replacement of fluorescent tubes with linear LED replacement lamps.	50 %	Lighting control	14 %
Thermal comfort criteria (adaptive comfort)	20 – 40 %	Window control (natural ventilation)	11 – 12 %
HVAC control (occupancy/thermal comfort)	30 – 52 %	Plug load control	21 %

Table 2 – Energy efficiency measures for commercial buildings.

5. Conclusions and further work

This paper has reviewed a business model enabling to deliver energy efficiency as a service in commercial rented buildings and it has been shown that the optimal revenue share for building owners maximising their NPV decreases when the renters' rebound effect increases. The rebound effect related to the installation of a PV-system in a large shopping centre has been analysed using available data. A robustness check of the rebound effect associated with HVAC utilisation will be performed when additional data such as solar irradiation and cooling load will be available. Furthermore, bespoke training workshops will be designed to prevent or limit changes in energy consumers' behaviours following installation of energy efficiency measures.

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