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Building energy retrofit-as-a-service: a Total Value of Ownership assessment methodology to support whole life-cycle building circularity and decarbonisation

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ABSTRACT

The regulatory drive to accelerate the clean energy and circular economy transitions in the European building stock is currently failing to overcome systemic implementation barriers. These barriers include high initial investment costs, misaligned financial incentives among stakeholders, and the relatively low cost of less sustainable energy and materials. A Product-Service Systems (PSS) approach could successfully overcome many of these barriers by (1) outsourcing capital investment, as well as financial and technical risks, (2) providing shared economic incentives to collaborating stakeholders, and (3) retaining extended producer responsibility and ownership over materials and products. However, PSS is still not seen as a viable business model when compared to both a standard "ownership" contract and a "no-retrofit" scenario. This paper proposes a Total Value of Ownership (TVO) method to evaluate the financial performance of a building energy retrofit in terms of Net Present Value, comparing a matrix of scenarios. Results show that – when accounting for capital and opportunity costs tied to alternative investments, internalising externalities, and monetising soft values such as user productivity and property value – a PSS model can deliver the highest NPV. Furthermore, results show that a PSS alternative can act as a positive future-proofing strategy to safeguard the building owner's position in the face of uncertain future market indicators and carbon taxation. Recommendations for policymakers, investors, financiers, building owners, and end-users are presented to identify the economic value of PSS contracts, leading to better-informed decisions which can accelerate deep energy retrofit of the building stock.

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Motivation, context, and background

The relevance of building decarbonisation

In 2018, the European Commission (EC) published a communication confirming "Europe's commitment to lead in global climate action, and to present a vision that can lead to achieving net-zero greenhouse gas emissions by 2050 through a socially-fair transition and in a cost-effective manner" (European Commission 2018). In March 2020, the EC presented a proposal to enshrine the 2050 carbon neutrality target for the EU into law (European Commission 2020a). The expected contribution to this target from the construction and infrastructure industry is framed in the EU Clean Energy Package and in the EU Circular Economy Package:

The EU Clean Energy package requires member states to prepare national policy measures to achieve high renovation rates, smart and decarbonised buildings with reduced energy consumption, and supplied with renewable energy sources (European Commission 2020b).

The EU Circular Economy Package, adopted in March 2019 in its 4th version, states the aims of maintaining the value of products and materials for as long as possible, minimise waste and resources use, and use products again after they reach their "end-of-life" to create further value (European Commission 2019a).

Approximately 800 million tonnes of partially recyclable and reusable construction and demolition waste are generated every year (European Commission

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2019b), but the challenge of whole life cycle building decarbonisation in Europe mainly concerns the 25 billion m^2 of usable floor space that has already been built. As is well known, renovation rates have consistently remained below target (Economidou *et at.* 2011), while the average share of renewable energy supplied to buildings in the European Union remains around 20% (Eurostat 2021).

Barriers & opportunities

Extensive literature has validated that existing buildings can reach net carbon neutrality through the use of market-ready, affordable technologies, both from the point of view of embodied as well as operational carbon (Xing *et al*. 2011, Lannon *et al*. 2013, Ferreira *et al*. 2016, Almeida & Ferreira 2017, Conci *et al*. 2019). Common strategies include the use of biomass (i.e. timber) as construction material, combined with highly insulating envelopes, energy-efficient thermal energy systems (such as heat pumps), and renewable energy generation (such as photovoltaic cells).

Despite available technologies, demand for both retrofitted and new carbon neutral buildings is low. Extensive interviews and surveys among individual stakeholders have identified two main barriers to deep energy retrofits: a lack of access to initial capital, and conflicting incentives in how to invest it (Azcarate-Aguerre *et al*. 2017, Build UP 2020).

Long-term property assessed clean-energy (PACE) investment funds, which pre-finance renovation measures with guaranteed pay back from energy savings (www.europace2020.eu) have been developed to incentivize building owners and occupiers to invest in building decarbonisation by offsetting initial capital needs. This approach resulted in the successful large-scale deep energy renovations of up to 10,000 apartments at a time (Energiesprong 2019), but a challenge often encountered is that initial capital costs are not compensated over the project's service life, resulting in a net loss for the investor. This can be due to market forces and/or regulation (e.g. regulatory limits on rental prices or markets with fluctuating valuation of energy labels and other performance certificates (Holtermans and Kok 2019)); due to split incentives (e.g. when landlords pay for the renovation but tenants pay for operational energy costs (Melvin 2018); or because energy cost savings fail to materialise to the required extent (e.g. user rebound effect (Bourrelle 2014)).

Reaching carbon neutrality in real estate projects also adds a layer of complexity to the already time-consuming decision-making structure of building renovations: few building professionals have the skills to plan and deliver a carbon-neutral building, and few clients are willing or equipped to contextualise and assess the additional evaluation criteria. This additional effort is not monetizable as real estate valuation processes do not – at present – fully or reliably account for the value of sustainability, neither in terms of energy consumption nor of material circularity (Warren-Myers 2013; Rooplal Utmani 2021). Several EU-funded projects such as Envest (2019–2021), LAUNCH (2019–2021), and TripleA-reno (2018–2021) aim to accelerate the demand for deep energy renovations. They focus on the investor and building owner's perspective by addressing capitalisation, added-value standardisation, and user-acceptance barriers.

As recognised by the EC, circular strategies can generate new revenue streams, because circularity hinges on closing material loops – i.e. the secondary revalorisation of the stock – which means that "waste" materials and components are turned into new products at the end of (each of) their service lives (Alhola *et al*. 2017, Hopkinson *et al*. 2018, Ajayebi *et al*., 2019, Ajayebi et al., 2020, City of Helsinki 2019). This should improve on the financial balance of net-zero carbon buildings. This potential new revenue stream, however, has so far not motivated a large uptake in this kind of projects, mainly due to the fact that the market for secondary material streams is not yet mature or predictable, rendering the long-term value trend of such components and materials uncertain.

Policy could help, first and foremost by regulating negative externalities, such as carbon emissions, on the grounds of being a societal hazard and a threat to the wellbeing of present and future generations. Another important step could be to invest public funds in increasing construction professionals' skills and capabilities in delivering carbon neutral buildings, for example in planning and building with wood, designing for disassembly, remanufacturing, carbon accounting, and cost-benefit analysis tied to Environmental and Sustainability Goals (ESG) credit ratings. A notable actor in this area of work is the Ex'tax Foundation (www.ex-tax.com), which is helping countries to pioneer these approaches. Yet another promising policy shift – more radical but which is gaining traction – is an increase in taxation of material resources and a decrease in taxation of human labour (Stahel and Clift 2016, Milios 2021). This measure could significantly improve the financial case for material resource recovery in advanced economies where the cost of labour is a significant barrier to effective material circularity (Matsumoto *et al*. 2016, Milios *et al*. 2019).

There is thus a clear need for a collaborative approach that aligns levers of technology, finance and economics, and policy and regulation. Having established the role of technology and assuming policy will move slowly, we now focus on the economic and financial levers, which could be activated through a Product-Service System approach.

Product-Service Systems: a potential energy-retrofitting catalyser

Product-Service Systems (PSS) are a category of business models which aim to shift the focus of value in economic transactions away from that of tangible material products, and towards that of the intangible functional performance delivered by these products. PSS could act as a catalyser of deep building energy renovations by (Figure 1):

1. *Offsetting* the initial investment to an external financing party, therefore unlocking access to external capital while avoiding internal opportunity costs;
2. *Tying* long-term performance-based contracts to bespoke sets of indicators, like comfort and environmental impact, so that externalities and co-benefits can be effectively monetised; and
3. *Retaining* materials ownership with the supplier (or supplier consortium), who is responsible for their performance. Thus incentivising durability, reparability, and the recovery of residual value at the end of components' service-lives – i.e. a circular use of resources.

Figure 1. Three aspects of Product-Service Systems that could potentially accelerate the deep energy renovation of the built environment while enabling product and material circularity.

PSS is not a new concept in the construction and real estate management fields. Its overarching value proposition, organisational implications, and sustainability potential have been recognised for over two decades (Leiringer and Bröchner 2010). Numerous authors have identified and highlighted a natural alignment between PSS, the Circular Economy, and environmental sustainability (Stahel 1997, Mont 2002, Vezzoli *et al*. 2017). Nearly twenty years later, an increasingly mainstream interest in the Circular Economy has brought the concept of PSS to the foreground of a broader societal and industrial debate, at least in the Northwestern European context.

Three main uncertainties regarding the applicability and feasibility of PSS have been identified to date: the readiness of companies to adopt them, the readiness of consumers to accept them, and their environmental implications (Mont 2002). A challenge to its wider implementation has been recognised as the lack of quantitative tools to determine the total value delivered by PSS offerings (Baines *et al*., 2007, Wang *et al*., 2011). These uncertainties and challenges remain largely unsolved: suppliers are still mostly reluctant to invest resources in a transition for which there is still no widespread demand; consumers lack the tools to determine whether a PSS alternative is beneficial to them beyond the initial investment and; environmental benefits remain largely untested as few companies have implemented PSS, and those which have rarely publish specific information on its mid- to long-term financial and environmental results.

In the last 10–15 years a small number of authors have proposed economic evaluation methodologies for the development and implementation of different PSS models.

These analyses have been characterised as: (a) highly specific to their regional or sectoral context, with limited transferability to other contexts; (b) mostly reliant on individual case-studies, or a small sample thereof; and (c) largely focussed on abstract sources of customer added value (i.e. soft values) rather than hard monetised performance evaluation (van Ostaeyen 2014, Reim *et al*. 2015).

Several methodologies have focussed on supply-side readiness by proposing methods for evaluating PSS-related cost-savings potential for the manufacturer and service provider. They found that PSS savings could theoretically result in optimised commissioning costs to the customer, however, suppliers have also been rated as not always ready to reap such savings (Lind and Borg 2010, Straub 2010, van Ostaeyen *et al*. 2013).

This paper focuses instead on the demand-side readiness by proposing a method for evaluating PSS-related cost savings potential for the commercial real estate owner and investor. Commercial building owners are defined as those for whom the ownership and exploitation of real estate represents the core business, as opposed to public or corporate real estate owners for whom the building acts as an operating asset to facilitate and enable their core processes and/or value creation activities. The method aims at supporting decision-making among both technological and contracting alternatives by providing an evaluation of Total Value of Ownership (TVO) in terms of Net Present Value (NPV) over a specific time frame for different building energy retrofit scenarios. A TVO analysis allows the assessment of specific impacts tied to a PSS approach thanks to the inclusion of whole life cycle timeframe as well as "soft" values and co-benefits. Net Present Value allows for the evaluation of uncertain future developments through a sensitivity analysis, overcoming the barriers of traditional Life Cycle Costing (LCC) methodologies when dealing with factors such as the (future) value of sustainability, externalities, subjective strategic fit, and split ownership (Gluch and Baumann 2004, Goh and Sun 2016)

Method and materials

Design and structure to test the hypothesis: Product-Service Systems have the potential to unlock financing for building decarbonisation

The study is structured in three steps:

1. Develop a TVO-based evaluation methodology to compare a PSS energy retrofitting contracting solution against alternative contracting scenarios. We will subdivide the evaluation into a TVO sub-total including only "hard" monetary values and a TVO + total including selected "soft" values as well.
2. Statistically test this methodology using an archetypal retrofit project based on industry-average data for the Dutch commercial real estate and construction sectors. The use of a statistical model, rather than a (selection of) case-study building(s), aims to ensure our results are as broad and representative as possible, and not determined by the specific project and client characteristics of the selected sample.
3. Perform a dynamic sensitivity analysis through a Montecarlo simulation to determine the extent to which the different parameters influence the financial investment performance of the TVO+. The parameters are selected as a combination of the most determinant ones in the archetypical static analysis and the most widely ranged for different investor profiles (private, corporate, public).

TVO-based evaluation methodology

Total Value of Ownership (TVO) is the sum of a project's total costs and its total value, including capital expenses, such as initial investment in year zero and opportunity costs, and indexed future cash flows over each planned year of operation (Davis *et al*. 2005, van Ostaeyen 2014), but also other tangible and intangible factors as determined by the decision-maker. The scenario with the highest TVO is the most financially attractive, for the investor who needs to choose between alternative projects which offer equivalent utility performance.

A basic approach to the most tangible TVO factors is thus determined by the formula:

$$\text{TVO} = -\text{Px} - \text{Ox} - \text{Mx} - \text{Ex} + \text{Tv} + \text{Rv}$$

Where:

P_x is the capital cost of the project's **initial investment in €/m^2 NFA** plus the region's bank loan servicing cost

O_x is the **opportunity cost of capital** for the project's initial investment in €/m^2 NFA at the region's Weighted Average Cost of Capital (WACC)

M_x are the **indexed future maintenance costs** SUM of M_1, M_2, $M_3, \ldots M_x$ in €/m^2 NFA, plus the cost of deferred maintenance in a no-renovation scenario.

E_x are the **indexed future energy costs** SUM of E_1, E_2, $E_3, \ldots E_x$ in €/m^2 NFA

R_v is the **indexed value of rental revenue** SUM of R_1, R_2, $R_3, \ldots R_x$ in €/m^2 NFA

T_v is the **indexed transactional value of property appreciation** SUM of T_1, T_2, $T_3, \ldots T_x$ in €/m^2 NFA

The extended approach including softer or less tangible indicators of value, proposed by this study as TVO + analysis, is determined by the formula:

$$\text{TVO}+ = \text{TVO} - \text{Sx} - \text{Hx}$$

Where:

S_x are the **indexed shadow carbon costs** SUM of S_1, S_2, $S_3, \ldots S_x$ in €/m^2 NFA

Table 1. Categorisation of technical and contractual strategies evaluated.

Project options	"Business-As-Usual" Building (no intervention)	Net zero carbon Building (after retrofit)	Net zero carbon Building (after retrofit)
Ownership financing	Ownership financing	Ownership financing	PSS financing

Table 2. Initial investment and opportunity costs parameters.

	Parameter	Functional Unit	BaU	Retrofit (ownership)	Retrofit (PSS)	Source
	EPC label	Grade	E	A	A	Arcipowska et al. 2014
	Primary Energy use	kWh/m^2 NFA/a	265.00	50.00	50.00	Filippidou et al. 2017
	Net floor area	NFA	2.000	2.000	2.000	
	Planning & PM (15% of construction)	€/m^2 NFA	N/A	−€ 52.05	−€ 52.05	
	Façade retrofit	€/m^2 NFA	N/A	−€ 128.00	−€ 128.00	*COBOUW, 2020*
	Heat pump energy system retrofit	€/m^2 NFA	N/A	−€ 219.00	−€ 219.00	*COBOUW, 2020*
	Depreciation over 30 years	%	100%	100%	70%	
Px/Ox	**Initial investment**	€	N/A	**−€ 399**	**−€ 399**	
	Asset-backed loan (mortgage) index (10-year fixed)	%	1.60%	1.60%	1.60%	https://www.hypotheekvisie.nl/hypotheek-berekenen/hypotheekrente-vergelijken
	WACC commercial sector	%	6.30%	6.30%	6.30%	Ortner et al. 2016

H_x are the **indexed costs of a decrease in staff productivity** due to poor indoor comfort, SUM of H_1, H_2, $H_3, \ldots H_x$ in €/m^2 NFA

C_v is the **indexed material or components value recovered** through, respectively, recycling or remanufacturing activities, in % of original component value indexed at the end of service life.

We use the TVO and TVO + formulas to evaluate the following matrix: a "Business-as-Usual" (BaU) scenario, in which no energy renovation takes place, and a decarbonised "Net-Zero" building energy retrofit project, financed either through a standard ownership contract, or through a PSS contract (Table 1).

Parameters and boundary conditions for selected archetypical case-study

In this section we summarise and justify boundary conditions as well as our selection of values to apply the TVO-based evaluation method to an archetypical case-study project.

Boundary conditions – geography. The range of financial parameter values central to this calculation varies across European countries without a recognisable reciprocal trend. Notably these financial parameters are the Weighted Average Cost of Capital (WACC), which is the average cost of debt (bank loans) and equity (investor's capital) for commercial projects, and labour costs. Both influence initial investment, opportunity costs, and maintenance costs. For this reason, we selected the Netherlands as a proxy for a Northwestern European country-average evaluation, due to its comparable climate, socioeconomic, and financial indicators (Stein 2016), as well as its solid databases documenting building stock and market prices. To note is that WACC averaged 6.3% in the Netherlands and 7.3% in the EU-28 as per the results of the Intelligent Energy – Europe project's DIA-CORE (Ortner *et al.* 2016).

Boundary conditions – time. We perform the quantitative evaluation of Total Value of Ownership (TVO) over the next 30 years to align the analysis with the EU-wide target of carbon neutrality by 2050.

Parameters – initial investment and opportunity cost. Table 2 summarises Initial investment and opportunity costs parameters. To note is that for the analysis presented in this paper we select an average existing non-residential building, a category that comprises 39.3% of Dutch building stock (European Commission 2021) and has an average area of 2.000 m^2 (BPIE 2011, Sipma 2019).

Initial investment costs include planning and project management, materials and components, installations, and construction costs, all including Dutch 21% VAT. For the renovation, we use the Energy Performance Certificate (EPC) label – a rating scheme to evaluate the energy efficiency of buildings in the European Union (Arcipowska *et al.* 2014) – to characterise a building's energy-relevant physical characteristics. EPC labels range from G, the lowest, to A, the highest and most energy efficient. According to

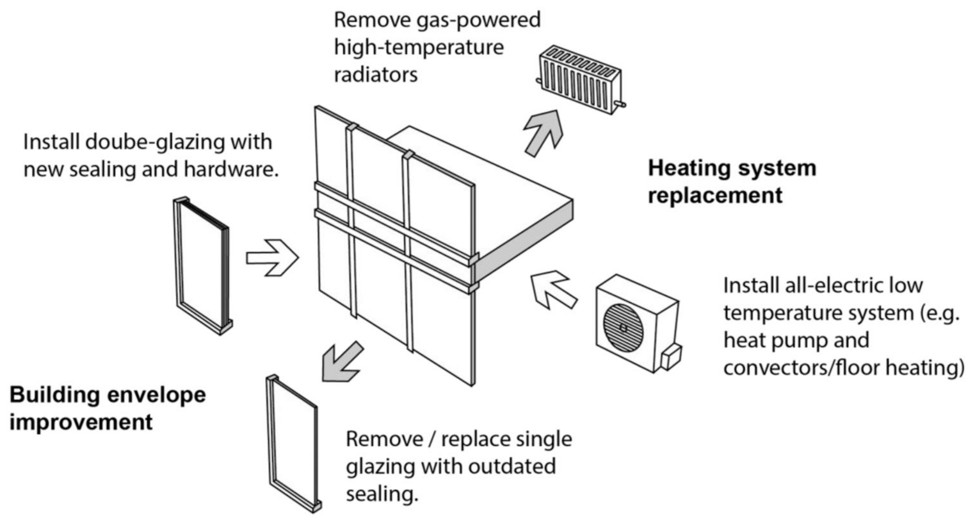

Figure 2. Technical sketch of implemented deep energy retrofit measures on the archetypal building. The study is applied to a generic, archetypal building based on broad statistical data from the Dutch context in order to overcome the highly specific (and thus non-representative) values of any specific case-study project or sample of projects.

Zebra2020 Data Tool by Enerdata the most common EPC label for non-residential buildings in the Netherlands is label "E," comprising 35% of the building stock. This value is consistent with the average for the 9 European countries providing data. An EPC label "E" translates to a primary energy consumption for heating and Domestic Hot Water preparation of 265 kWh/m^2/year (Filippidou *et al.* 2017). In buildings with EPC label "E," thermal energy is usually generated through boilers running on natural gas. An EPC label "A" building, in contrast, has a primary energy consumption for heating and Domestic Hot Water preparation of $<$50 kWh/m^2/year thanks to an insulated façade and typically generated through a heat pump system (Figure 2) (Engie.nl, 2012).

As defined by IEA Annexe 61 (Zhivov *et al.* 2017), a major building renovation project in which site energy use intensity has been reduced by at least 50% from the pre-renovation baseline is a "deep energy retrofit," so an improvement from EPC label "E" to "A" therefore represents a "deep renovation". We also include depreciation, which is tied to the service life of each component. For reference, EEFIG De-risking Energy Efficiency Projects (DEEP) Platform (https://deep.eefig.eu/) lists the initial investment to retrofit a non-residential building in the EU-28 at €88/m^2 floor area for the building envelope and €198/m^2 floor area for the HVAC system, while data from 8 EU countries provided by Zebra2020 Data Tool results in an average investment costs of €430/m^2 for a "deep renovation" of a non-residential buildings, so that this case falls within a realistic range.

Parameters – indexed costs. Table 3 below summarises Indexed parameters, which include maintenance costs, energy costs, rental value, and property value.

To note is that the price of energy for non-household consumers in the Netherlands is €0.039/kWh for natural gas, with EU-28 average being €0.032/kWh (Eurostat 2019a), and €0.09/kWh for electricity with EU-28 average being €0.12/kWh (Eurostat 2019b). 4) We assume that the "green power" provider uses the same rates.

A study by ING Real Estate Finance and the University of Maastricht found that the Dutch real estate market grants a 9.9% rental premium and a 8.6% property value premium to an EPC label A building compared to the average building (ING Real Estate Finance 2017). We use these factors to evaluate the potential increase in rental income and property value from improved EPC label for an average commercial property in the Netherlands, which has a gross rental income of €147/m^2 NFA and a property value of €1.235/m^2 NFA.

Parameters – soft values. Table 4 summarises shadow carbon costs, staff productivity costs, and recovered material or components prices.

For the embodied GHG emissions resulting from the energy retrofit of a non-residential building we take the average from a study evaluating a wide range of non-residential case-study buildings with wood, concrete, and metal façade constructions (Hildebrand 2014). We assume a credit for the next life of the component (offsetting the carbon emissions from virgin

Table 3. Indexed parameters.

	Parameter	Functional Unit	BaU	Retrofit (Ownership)	Retrofit (PSS)	*Source*
Mx	**Maintenance**	**€/m^2 NFA/a**	**−€ 3.86**	**−€ 3.86**	**−€ 3.86**	https://www.beheerenonderhoudkosten.nl/welkom
	Inflation index (1997–2020 CPI)	%	1.88%	1.88%	1.88%	*CBS.nl Consumentenprijzen (1997–2020)*
	Energy price	€/kWh	−€ 0.04	−€ 0.09	−€ 0.09	Eurostat 2021
	Gas index 30 years	%	1.90%	N/A	N/A	*Cost Estimation tool by FROnT - Fair RHC*
	Electricity index 30 years	%	N/A	1.40%	1.40%	*Cost Estimation tool by FROnT - Fair RHC*
Ex	**Energy costs**	**€/m^2/a**	**-€ 10.34**	**-€ 4.50**	**-€ 4.50**	*Zebra2020 Data Tool by Enerdata*
	Gross rental income	€/m^2 NFA/a	€ 147	€ 161	€ 161	ING Real Estate Finance 2017
	Rental price index Non-residential (XX years)	%	0%	2.50%	2.50%	NVM Business 2020
	Property price		€ 1.235	€ 1.341	€ 1.341	ING Real Estate Finance 2017
	Property price index Non-residential (XX years)	%	0.60%	0.60%	0.60%	NVM Business 2020

Table 4. Soft values.

	Parameter	Functional unit	BaU	Retrofit (ownership)	Retrofit (PSS)	*Source*
	Embodied CO_2	$kgCO_2e/m^2/a$	0.00	0.78	0.78	Hildebrand, 2014
	Operational CO_2	$kgCO_2e/m^2/a$	64.00	10.00	10.00	Netherlands Enterprise Agency (RvO) 2017
	Carbon credits price (EU ETS)	€/$kgCO_2e$	−€ 0.03	−€ 0.03	−€ 0.03	Carbon Pricing Dashboard, 2021
Sx	**Shadow carbon costs**	**€/m^2/a**	**−€ 1.92**	**−€ 0.32**	**−€ 0.32**	
	Shadow cost index	%	100 % until 2030. then tied to inflation			
	Average office employee brutto salary	€/year	−€ 41.300	−€ 41.300	−€ 41.300	https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83740NED/table?dl=1A6C1
	Average floor area per employee	m^2	23	23	23	Buitelaar et al. 2017
	Productivity loss	%	2%	2%	2%	Terrapin Bright Green 2012; Brager 2013
Hx	**Personnel costs**	**€/m^2/year**	**−€ 35.91**	**−€ 35.91**	**−€ 35.91**	
	High-grade recycling value	%	0%	10%	N/A	
	Remanufacturing value	%	0%	0%	30%	
	London Metal Exchange index (1985–2020)	%/year	4.63%	4.63%	4.63%	Tradingeconomics.com 2021
Cv	**Material circularity value**	**€/m^2**	**N/A**	**€ 34.70**	**€ 104.10**	

material extraction) of −30% in the PSS scenario. The operational GHG emissions are calculated using the GHG emission factor for Dutch power 0.413 $kgCO_2e$/kWh (RvO 2017), but, assuming the utility sector plays its part, in 2050 our target electricity system is carbon neutral. The average GHG emissions factor for the electricity consumption of the building with EPC label "A" between 2020 and 2050 is therefore 0.206 $kgCO_2e$/kWh, resulting in yearly GHG emissions of $50\,kWh/m^2 * 0.206\,kgCO_2e/KWh = 10\,kgCO_2e/m^2$/year over the 2020–2050 period. For reference, in the alternative case of a "green" power provider who can certify 100% electricity generation from renewable sources from the first year of operation. The carbon emissions of this scenario should therefore be accounted for using the factor for value-chain emissions for solar and wind power, which is 0.011 $kgCO_2e$/kWh, resulting in 0.6 $kgCO_2e/m^2$/year.

The hard-monetary cost of poor indoor comfort, and its effect on personnel health, well-being, and productivity, is the subject of much scientific debate. Estimates for economic losses resultant from staff absenteeism and presenteeism due to factors such as poor thermal comfort, insufficient lighting, poor air quality, are often in the range of 2–4% (Olesen 2005, Seppänen and Fisk 2006, Terrapin Bright Green 2012, Feige *et al*. 2013). For this study we use a conservative 2% loss, calculated over the average yearly salary of a Dutch office worker.

The current lack of strong secondary material and component markets, and the unpreparedness of the construction value chain to presently reabsorb the residual value of end-of-service components effectively – through recycling or remanufacturing activities – makes it difficult to project a monetary value for such recovery. Expecting such market failures to be corrected in the coming decades, because of both policy incentives and industry interest, we propose a worst-case 10% residual value of recycled materials – largely resultant from the long-term value increase trend observed in the London Metals Exchange index – and a best-case 30% value recovery for high-grade remanufactured components. Current examples from other industries point to value recovery through effective remanufacturing to be much higher than 30% (Santini *et al*. 2011).

Results

Results shows that the Net Present Value (NPV) of the investment after 30 years in the Basic TVO model is highest for BAU, followed closely by PSS contracting, while it is negative for Ownership contracting retrofit. This result falls in line with – and explains – the observable low retrofitting rates across the EU. PSS contracting results in a positive NPV because the potential financial profit from an alternative capital investment (i.e. the opportunity value of an alternative and independent project) over-performs the retrofit expenses, even after accounting for the additional setup and financing costs resulting from the outsourcing of the project's capital investment, as well as from the long-term technical management.

In the TVO + model, accounting for soft costs, the overall NPV of the project for the building owner/investor, is lower but still positive when retrofitting through PSS contracting, almost unchanged compared to Basic TVO when retrofitting through the ownership model, and strongly negative when no intervention is made (Figure 3).

Sensitivity analysis

Dynamic Montecarlo simulation using SimVoi add-in

For the sensitivity analysis through Montecarlo simulation using SimVoi add-in for Microsoft Excel we select the parameters most determinant to results of the static archetypical Dutch case-study building: Shadow Carbon Cost indexation (in years 1–10) and Weighted Average Cost of Capital (WACC) to determine Opportunity Costs. In addition to WACC, we also test the servicing cost of the loan as part of the Initial Investment to explore results from the point of view of different types of investors (private, corporate, public), for which this specific parameter can vary significantly.

Variable 1: *Shadow Carbon Cost indexation* is tested in two ranges: (1) A high indexation in the range of 2–100% over the first 10 years, which reflects the real externality costs which the IPCC has established as necessary to achieve climate-change mitigation goals (de Coninck *et al*. 2018).; and (2) A low indexation range of 2– 10% over the first ten years, which might be politically realistic but most likely insufficient to achieve sufficient systemic change.

Variable 2: *Opportunity Cost and Initial Investment* are tested in a range of values provided for WACC and servicing cost of the loan through an asset-backed loan index. WACC ranges between 2.5% (low-risk public funding) and 10.1% (high-risk private equity funding), with the most likely mean being the 6.3% average value used in the static simulation. The servicing costs are tested as an asset-backed loan index ranging between 1.5% (representing an owner-

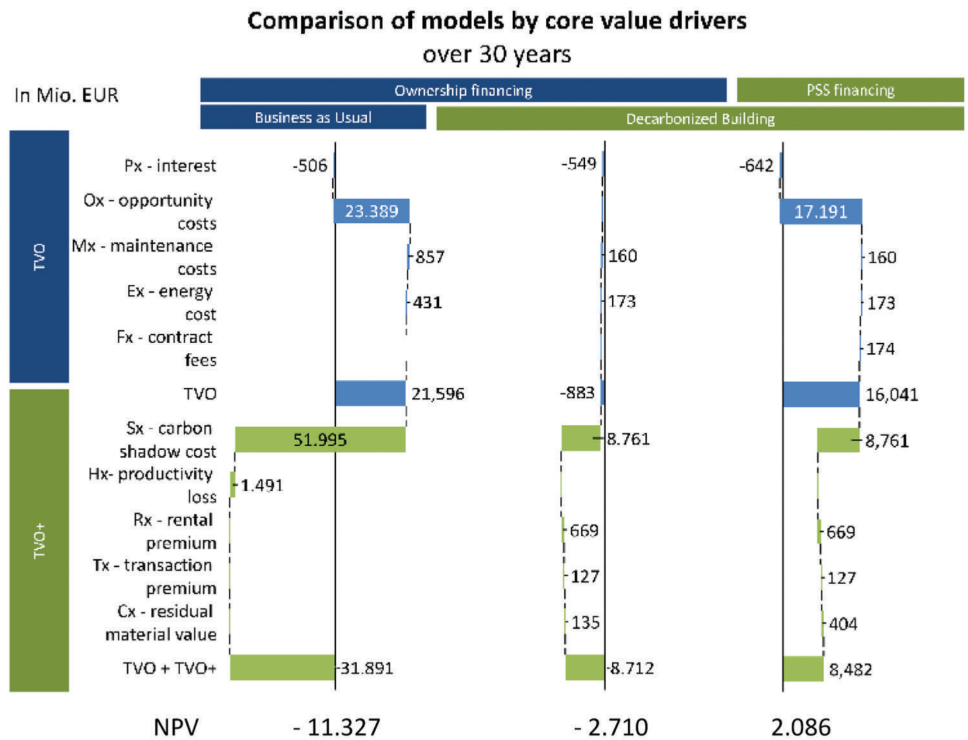

Figure 3. Total Value of Ownership comparison (in €/m^2) between three strategic scenarios for a potential deep commercial building energy renovation project over 30 years. The results of the 30-year cashflow are also summarised in terms of the NPV of each investment scenario.

	NPV after 1000 simulations				
Variable 1	BaU	OWN	PSS	NPV	
Low shadow costs indexation (2% to 10%/year over first ten years)	€ 6.970	€ 49	€ 6.045	Max	Variable 2
	€ 4.773	€ 10	€ 4.790	Mean	
	€ 982	-€ 122	€ 2.679	Min	
High shadow costs indexation (2% to 100%/year over first ten years)	€ 6.970	€ 49	€ 6.045	Max	
	€ 2.743	€ 291	€ 4.444	Mean	
	-€ 30.887	-€ 5.492	€ 2.679	Min	

Figure 4. Results of the dynamic Montecarlo simulation. The colour gradient highlights investment performance, with dark green representing the better-performing cases, yellow reprsenting intermediate results, and dark red representing the worst-performing cases.

occupied property) and 4.5% (high-cost rental mortgage) (DomiVest 2020).

Figure 4 shows the results of the Montecarlo simulation after 1000 simulations based on random triangular distribution function.

The results of the dynamic study show that the highest NPV (6.970 EUR/m^2) is found with the BAU (no intervention) scenario when Shadow Carbon Cost Indexation is 2.0%, WACC is 10.1% and loan interest rate is 1.5%. The same parameters also result in the highest NPV the PSS model can achieve, 6.045 EUR/m^2. In the case of the Ownership-based scenario the same best-case parameters result in a relatively small positive performance (49 EUR/m^2), as added values largely fail to compensate for opportunity costs. The worst performance for all scenarios occurs when Shadow Carbon Costs Indexation over the first ten years is at its highest (10% or 100% per year), and loan interest rate is at its highest (4.5%). The BAU scenario will then have its worst performance (−30.887 EUR/m^2) when the WACC is highest (hence highest opportunity losses). The Ownership and PSS scenarios will have their worst performance when the WACC is at its lowest (2.5%) resulting in NPV's of −5.492 EUR/m^2 and 2.679 EUR/m^2, respectively.

Conclusions

The static (archetypical Dutch case-study building) and dynamic (Montecarlo simulation) provide clear evidence that Product-Service System (PSS) financing of a deep building energy retrofit can act as a future-proofing alternative for building owners and investors. It allows them to still benefit from the opportunity value of alternative investments by unlocking (part of) the initial capital – or credit – available to them. It also allows owners to benefit from hard and soft added values such as a premium on rental income and transactional value due to better energy and indoor comfort performance. Meanwhile, it limits the investment decision's sensitivity to potential losses caused by decreased user productivity (e.g. due to poor indoor comfort) or by an increase in shadow costs (e.g. from higher carbon taxation resultant from governance changes).

The Montecarlo simulation shows that, under most conditions and when accounting for at least present-level carbon taxation, the PSS retrofit can be the safest strategic option. Under specific conditions (i.e. very low carbon tax indexation and opportunity value possibilities), Business-as-Usual (BaU; no intervention) performs best, but PSS still provides the best Mean and Minimum performance results, while achieving Maximum (best-case) results within a reasonable range of the BaU scenario.

The results would point to a PSS retrofitting alternative being a promising strategy to:

1. *Overcome decision threshold barriers:* For example, from investors who are not considering a deep energy retrofit due to the opportunity cost of using their potential leveraged capital for a more attractive or more core-business-related investment, and
2. *Decrease sensitivity to market conditions*, by limiting the range of financial performance of the retrofit investment, particularly on the Minimum (worst-case) end, while providing futureproofing to uncertain changes in policy such as carbon taxation.

The ownership-based retrofit scenario shows a mostly neutral performance, meaning the value created by the retrofit is in most cases offset by its capital costs and foregone opportunity value. This represents a risk to the average investor in case the added values (e.g. rental income and transactional value) fail to materialise due to worse-than-expected market conditions. Again, this explains the empirical evidence of real estate market across Europe, and the constant failure to meet deep energy retrofitting quotas through traditional decision-making and project finance means.

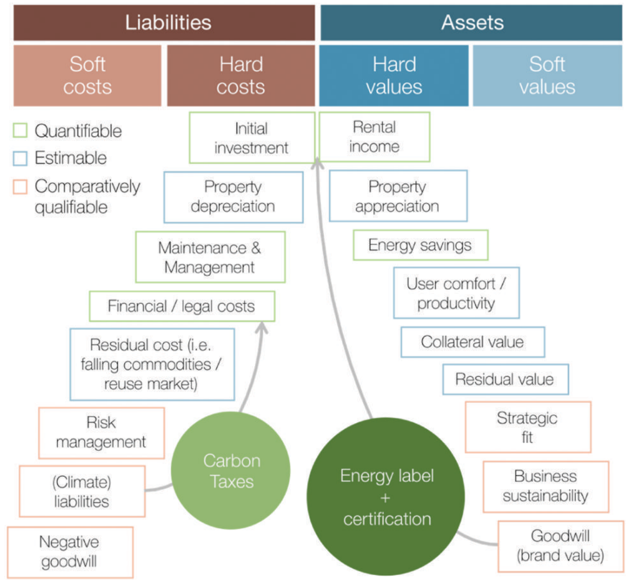

Figure 5. Non-exhaustive diagram of soft and hard values and costs which the authors recommend should be further studied and standardised. Policy instruments such as energy labelling and carbon taxation, and market instruments such as commercial certification standards are shown as examples of methods for the negative (cost) and positive (value) monetisation of soft parameters.

Policy recommendations and research limitations

In view of the results, the authors recommend developing standardised valuation models which account for energy and carbon savings, circular use of resources, increased rental income potential and property value, and other hard and soft costs and values. This to enable *monetisation of co-benefits* (or co-liabilities) that would incentivize capital flow towards performance-based building energy retrofit solutions (Den Heijer, 2013). This paper proposed a Total Value of Ownership (TVO) methodology for accounting for a specific set of values during the investment analysis process. While regional average figures were used, the authors acknowledge that in the case of both hard and soft values and costs, the actual figures used in an investment analysis are deeply specific to each type of building owner down to the individual organisation.

Figure 5 presents a first approach, and non-exhaustive list of hard and soft values and costs which the authors believe should be standardised and considered when making building (retrofit) investment decisions, and which should therefore be the focus of further study.

Only the individual characteristics and goals of an organisation can determine the value that different benefits and co-benefits have in the process of pursuing these goals. For example, corporate and public real estate owners are less likely to benefit from the potential rental income increase resultant from a better-performing building, as these organisations tend to be owner-occupiers of their buildings. Increase in property value, however, can still be considered as a hard benefit, since the building can be used as collateral for other investment projects the organisation might want to undertake in the future. The benefit of the approach presented in this paper is to account for: a. opportunity cost (and value) of alternative financing models, and b. monetised softer values which are usually considered only as abstract (but financially irrelevant or uncertain) co-benefits. The use of a statistical model based on Dutch national average figures – rather than a (set of) specific case-study building(s) – aims to account for the individual characteristics of each building owner and their specific value assessments. Any size of case-study building dataset would still represent only a limited sample with non-replicable results.

To overcome the barrier of higher Net Present Value (NPV) for no intervention scenarios, policy could help by demanding periodic technical reporting from owners of currently financed (e.g. mortgaged buildings) and penalising them for deferred maintenance, on the grounds that it will result in loss of value or higher future reinvestment requirements.

Lowering capital costs for projects that meet a certain decarbonisation performance or material circularity objective is another powerful tool available to decision-makers in public policy, as well as to investors such as banks, to increase demand for such interventions.

In the case of soft costs such as user comfort and performance, which are the subject of scientific debate, the authors propose that building owners use an inverse approach: Namely, to calculate at which cost of personnel productivity drop or shadow carbon taxation does the decision not-to-renovate become untenable. Such risks can then be considered when making long-term strategic decisions.

Because commercial parties generally have a high Weighted Average Cost of Capital (WACC), the costs of externalising energy retrofits trough PSS might not be drastically different compared to financing the entire project themselves. In the case of this type of owner, whether public or corporate, the attractiveness of PSS models lies in ease of processes in the achievement of soft social and environmental values related to their real estate portfolio. The methodology applied in this paper can be adapted for use in residential buildings. In this case the authors have decided not to do so since residential buildings are both technically (i.e. solid walls rather than curtain walls) and administratively (i.e. decentralised rather than centralised financing and decision-making) different from commercial ones, and the two sets of results would render the outcomes of this study too complex and confusing.

Finally, to upscale a PSS financing model for building retrofits and through it enable the transition to a circular economy, it is crucial to (1) develop standardised contracting and financing models to lower setup and management costs and (2) develop a track record of implemented PSS models. This will support their bankability and insurability, i.e. lower interest rates and financial premiums to cover risk and uncertainty. Previous work (Azcarate-Aguerre *et al*. 2018) has highlighted that it is unlikely for façade suppliers to be able to pre-finance Facades-as-a-Service (a sub-type of PSS) offerings. This restriction sets service providing parties in the construction industry apart from the great PSS transition success cases of other sectors *(*van Ostaeyen 2014*)* and illustrates the need to create well-founded financial cases for third-party investors and other financial institutions.

Regulatory measures, corporate responsibility initiatives and emerging societal trends can support each other. This can allow for rapid change as demonstrated – for instance – by the successful Energy Labelling of Buildings (EU Directive 2002/91/EC) system being replicated in many parts of the world.

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