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Beyond Green Visions: Financing and Business Models for Climate-Resilient and Biodiverse Urban Regeneration in Thessaloniki

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Abstract

Nature-based solutions (NBSs) are central to urban climate-neutrality strategies, but their implementation still lags behind policy ambition. One reason is that most NBS benefits are public goods and rarely generate direct revenue, so we know far less about the institutional and financial conditions needed to deliver them than about their ecological performance. This paper develops a business model framework linking NBS interventions to financing and governance configurations, applying established NBS typologies and the Pestoff Triangle of state, market, and community provision to thirteen interventions across eleven sites in the Railway District of Thessaloniki, Greece. The interventions are organised into five business model categories: public space greening, private space upgrades, public–private hybrids, building retrofits, and renewable energy. Their financing logic is shaped less by intervention type than by ownership structure and stakeholder configuration. To address this gap, we followed category-specific blended finance strategies combining grants, private investment, regulatory incentives, and community resources, underpinned by stewardship-oriented governance. The findings suggest that scaling NBSs depends less on technical readiness than on institutional capacity to match financing and governance to local ownership and stakeholder contexts, offering a pathway from climate-neutrality strategy to implementable urban regeneration.

Keywords: nature-based solutions (NBSs); business models; urban regeneration; climate neutrality; stakeholder governance

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1. Introduction

Cities worldwide are facing increasing pressures from climate change, biodiversity loss, environmental degradation, and growing socio-economic vulnerabilities [1]. Rising temperatures, more frequent extreme weather events, increased flood risks, and deteriorating urban ecosystems have intensified the search for approaches capable of simultaneously addressing environmental, social, and economic challenges [2,3]. In response, nature-based solutions (NBSs) have emerged as a central component of contemporary urban sustainability and climate adaptation strategies [4], capable of delivering carbon sequestration, stormwater management, biodiversity enhancement, urban cooling, air quality improvement, and well-being benefits [5,6]. NBSs now feature prominently in European policy,

including the European Green Deal [7], the EU Biodiversity Strategy [8], the New European Bauhaus [9], and the Mission for Climate-Neutral and Smart Cities [10,11], with cities increasingly embedding green infrastructure and ecosystem restoration into strategic planning and urban regeneration frameworks [12].

Despite this policy attention, a significant implementation gap remains between ambitious urban sustainability visions and their delivery on the ground [13]. Considerably less attention has been paid to the institutional and financial conditions for NBS implementation than to their ecological performance and technical design [14]. Many regeneration strategies identify promising interventions; however, only a fraction progress to implementation, undermined by financial constraints, fragmented ownership, governance complexity, and limited stakeholder coordination [13]. This gap is particularly pronounced in densely built environments, where NBS interventions span multiple actors and competing land uses, and where the benefits generated, in relation to flood protection, urban cooling, biodiversity enhancement, and property value uplift, are dispersed across stakeholder groups and rarely translate into appropriable revenue for individual investors. The paper argues that this mismatch between value creation and value capture is one of the principal barriers to large-scale NBS deployment, and the resulting dependence on public funding leaves opportunities for private investment, community participation, and blended financing underdeveloped [13,15].

Addressing this mismatch requires moving beyond the technical design of interventions toward an understanding of how NBSs can be made financially viable, institutionally embedded, and operationally sustainable—that is, toward a business model perspective capable of specifying how costs, benefits, risks, and revenues are distributed across public authorities, private investors, property owners, and communities [16]. Existing research in this space remains fragmented, however, typically examining individual financing instruments or isolated case studies rather than systematically linking different types of NBS interventions to corresponding business model configurations [17].

This paper examines the relationship between urban NBS interventions, stakeholder structures, and financing mechanisms within the context of climate-resilient urban regeneration, focusing on the Railway District of Thessaloniki, an area undergoing transformation associated with mobility investments, neighbourhood regeneration, and the city's climate-neutrality agenda. Its diverse portfolio of potential NBS and renewable energy interventions, spanning public space, private property, shared residential environments, educational facilities, and community assets, provides an ideal setting for exploring alternative financing and governance arrangements. The objective is to develop a framework linking NBSs to appropriate business models and financing configurations. To this end, it sets out the financial logic underlying NBS investment and the CAPEX/OPEX asymmetry that constrains it, and reviews the business model typologies through which that logic has been operationalised in the literature, before both are applied to the Railway District of Thessaloniki case study.

The contribution is threefold. First, the paper shifts attention from the environmental performance of NBSs towards the financial and organisational mechanisms that enable their implementation. Second, it develops a spatially grounded typology of NBS business models, showing how ownership structures, intervention scales, and stakeholder configurations shape financing and governance arrangements. Third, it offers planners and policymakers a route from climate-neutrality strategy to implementable projects. In doing so, the paper contributes to the debate on how cities can move beyond green visions towards financially viable pathways for sustainable urban transformation.

2. Conceptual Framework and Methodology

2.1. The Financial Logic of Nature-Based Solutions

Nature-based solutions are increasingly recognised as cost-effective instruments for addressing urban climate challenges. However, unlike conventional grey infrastructure, they generate value across multiple dimensions simultaneously, regulating microclimates, reducing flood risk, supporting biodiversity, and enhancing public health and well-being. This multifunctionality is at once their greatest strength and their principal financing challenge. Most NBS benefits are non-excludable and non-rival in character, exhibiting the classic properties of public goods. Because these benefits are shared across many stakeholders but do not translate into direct revenue streams, NBSs struggle to attract private investment on conventional commercial terms and remain heavily dependent on public grants, which are often insufficient to sustain ecological functioning over the long project lifecycles that NBSs require [18,19].

To understand the financial logic of NBSs, it is essential to consider costs and value across the full intervention lifecycle. Capital expenditure (CAPEX)—covering design, installation, and land preparation—is generally the most visible component and the phase most accessible to public grants and EU instruments. Operational expenditure (OPEX), encompassing maintenance, irrigation, monitoring, and related activities, presents a more persistent and structurally underfunded challenge: while the intrinsic value of NBSs appreciates over time as ecological systems mature (unlike grey infrastructure, which depreciates), their functioning depends on continuous stewardship that frequently goes unfunded once initial project grants are exhausted [19,20]. This temporal asymmetry, in which CAPEX is relatively accessible, but OPEX remains chronically underfunded, constitutes the key structural challenge in NBS financing. Figure 1 schematically illustrates this lifecycle dynamic, tracking relative value/cost across three phases: planning and design (Phase A), capital investment (Phase B), and operation and stewardship (Phase C). Both NBSs and grey infrastructure show comparable initial costs during planning and construction, but their trajectories diverge sharply once the asset becomes operational: grey infrastructure depreciates steadily over time, whereas NBSs' value appreciates as ecosystems mature, provided that the OPEX gap in Phase C is bridged through sustained stewardship. The break-even point marks the moment at which accumulated NBS value overtakes that of the conventional alternative, underscoring why financing arrangements that stop at the capital investment stage systematically undervalue nature-based interventions. In addition, transaction costs (e.g., stakeholder engagement, governance complexity, permitting) and opportunity costs (i.e., foregone alternative land uses) add further layers of financial complexity, particularly in dense Mediterranean urban environments where land is scarce and competing pressures are acute.

The undervaluation of the long-term benefits mentioned above is compounded by the absence of commonly accepted and operational indicators capable of capturing long-term appreciation in the first place. Without robust metrics for ecosystem services, avoided climate risks, or public health improvements, conventional investment appraisal frameworks systematically undervalue NBSs relative to grey alternatives. Thus, this measurement gap reinforces the investment gap: investors and public authorities alike struggle to compare NBSs with competing options, limiting their ability to construct compelling financial cases or justify the blended financing arrangements that NBSs genuinely require [18,21].

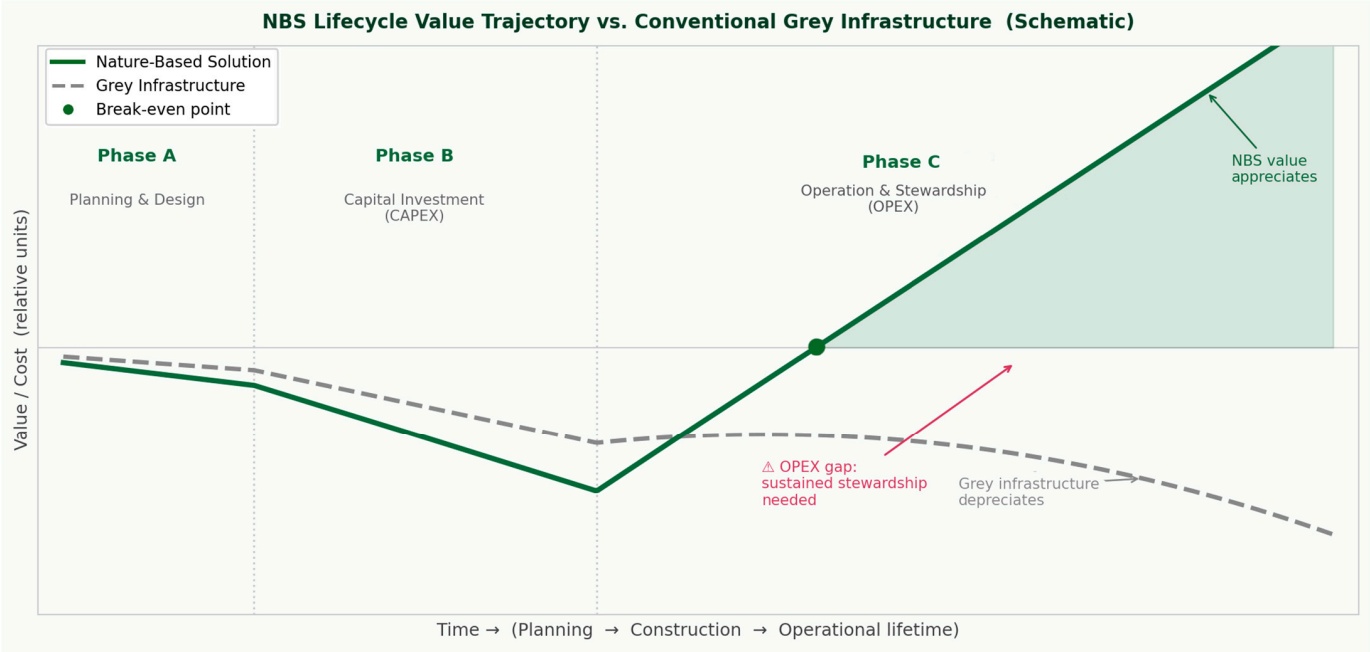


Figure 1. NBS lifecycle value trajectory compared with conventional grey infrastructure. Source: Authors, adapted from McQuaid [19] and UNEP-CCC [20].

In response to these challenges, the recent academic and policy literature has increasingly applied business model theory as an analytical lens for NBSs. Business models for NBSs are structured frameworks that explain how a given intervention creates, delivers, and captures environmental, social, and economic value, and how this value logic translates into a sustainable financing and governance model [18,22]. In contrast to conventional commercial business models, NBS business models must account for the public-good nature of most ecosystem services, thereby requiring hybrid financing arrangements that combine public, private, and community resources. This paper builds on established typologies developed within EU research initiatives, including the Naturvation business model catalogue [22], the Connecting Nature NBS Business Model Canvas [19], and the NAIAD collection of financing instruments [18], applying them to the Railway District of Thessaloniki.

Accordingly, in this study, the term "business model" encompasses the processes through which value is created, delivered, and captured, together with the financing and governance conditions that support an intervention throughout its lifecycle. These conditions include the sources and instruments used to cover CAPEX and OPEX, the distribution of roles and responsibilities, the organisation of decision-making, and the coordination among the actors involved. Their combination shapes the implementation and long-term continuity of an NBS intervention.

2.2. NBS Business Model Typologies: A Framework Overview

The literature identifies several recurring archetypes of urban NBS business models, each associated with a distinct value proposition and financing logic [22,23]. Among the most broadly applicable to the context of our study area (see Section 2.3) are the following five models. The Risk Reduction model frames NBSs as avoided-cost investments in climate resilience: they reduce the financial risks tied to adverse environmental events, such as flood damage or extreme heat, justifying public expenditure or contributions from beneficiaries such as insurers or property owners. The Green Densification model exploits the documented tendency of urban greening to generate property value uplift in adjacent

areas, offering a mechanism through which developers and private owners can recover investment through enhanced real estate returns.

The Urban Offsetting model channels funds from activities generating environmental impact into NBSs as compensation: municipalities may require developers to pay into a dedicated green fund or implement NBSs on adjacent sites to offset the loss of permeable surfaces or green space. The Local Stewardship model, in turn, mobilises civic and corporate resources through bottom-up engagement. It relies on civic duty and corporate social responsibility, drawing on in-kind labour and modest financial contributions. A fifth archetype from the same Naturvation typology, the Vacant Space model, is also of particular relevance to the study area, given its mix of underused plots and informal parking. This model transforms underutilised urban land (e.g., abandoned plots, informal parking, residual intra-block spaces) into community green spaces at a low cost, unlocking latent land value where market pressures are weak and public provision is stretched.

At the structural level, these archetypes can also be positioned along the axes of the Pestoff Triangle [24], which maps initiatives across three institutional poles: public/state provision (city-led, publicly funded), private for-profit provision, and community-based provision. Section 3.4 applies this framework to position the five business model categories identified in the Railway District.

In practice, most NBS interventions combine elements from multiple archetypes. A public green corridor may simultaneously reduce flood risk (Risk Reduction), increase surrounding property values (Green Densification), and be maintained through local volunteer networks (Local Stewardship), while being financed through municipal land and EU grants (Public Provision). Recognising this mixed character, the present study avoids rigid one-to-one classification and instead identifies the dominant financing logic and the most relevant mix of value propositions as a starting point for examining how each intervention is configured within its specific spatial and institutional setting.

This transition from a general archetype to a locally viable configuration is less explicitly addressed by existing approaches, which establish the principal dimensions of an NBS business model and identify recurring value and financing archetypes. However, existing approaches provide less guidance on how ownership, value capture, and decision-making structures shape the applicable configurations across different sites. The framework developed here adds this configurational level of analysis by examining how asset ownership and control, value capture, stakeholder coordination requirements, and the distribution of CAPEX and OPEX responsibilities across the intervention lifecycle shape the financing and governance arrangements associated with different interventions. The five categories developed in the case study are therefore case-derived configurations whose conceptual contribution lies in making explicit the relationship between spatial and institutional context and business model selection.

2.3. Study Area: The Railway District of Thessaloniki

The intervention district is in the western part of the Municipality of Thessaloniki, and its boundaries are defined by Eleftherias Square, the Old Railway Station, Agioi Panton and Vasiliou Tzorlini street. The area is expected to undergo significant changes in mobility patterns and land uses due to the arrival of the metro and the upgrading of the railway station.

A significant part of the district retains the character of a residential neighbourhood, with old social housing estates and apartment buildings of moderate height, usually three to four floors, including the ground floor. Around these buildings, several open spaces remain undesigned, underused, or poorly maintained. Although many of these spaces

include permeable soil, they do not currently provide high-quality public or communal uses that respond to the needs of the local community.

The resident population is mainly lower-income, and living space per person is limited, particularly in former social housing complexes. The shortage of adequate private and communal space increases the importance of adjacent public and semi-public areas for everyday neighbourhood life. Apartment buildings also contain underused roofs and uncovered plots that could support ecosystem services, shared community spaces, and renewable energy generation. Due to the lack of private parking spaces in these residential buildings, and despite the development of the metro and 'OSE' (Greek Railways Organisation) railway network in the area, many open spaces are currently used for informal parking. Their physical condition is often complex, with uneven ground, slopes, subsidence, stagnant water, spontaneous vegetation, and unregulated car occupation. These conditions reduce accessibility and contribute to a general impression of abandonment, fragmentation, and urban degradation.

Existing urban squares, small parks, and roadside spaces also require targeted redesign to improve their performance and resilience during heatwaves, heavy rainfall, and other extreme weather events that are becoming more frequent and intense due to the climate crisis. The same applies to schoolyards, which are largely covered with cement and have limited planted areas, shade, and permeable surfaces. These spaces represent important opportunities for climate adaptation, nature-based solutions, improved accessibility, and the creation of more inclusive neighbourhood infrastructure. Representative examples of these existing conditions are shown in Figure 2.



Figure 2. Representative existing conditions in the Railway District of Thessaloniki: (**a**) vacant or underused space currently used for informal parking; (**b**) residual open space around a social housing complex; (**c**) sealed educational space with limited vegetation and shade; (**d**) streetscape with limited and discontinuous green infrastructure. Source: Authors' field survey.

A survey conducted in early 2024 identified eleven types of open spaces as potential areas for renovation with NBSs and RESs (Renewable Energy Solutions). These include the following (Figure 3): (1) *Vacant spaces and underused plots*, including areas currently

used for surface parking. (2) *Primary and secondary school grounds*, including courtyards, playgrounds, and open-air educational spaces. (3) *Higher education facilities*, including the School of Veterinary Medicine and surrounding open spaces. (4) *Urban squares* requiring climate adaptation to perform better during heatwaves, heavy rainfall, and other extreme weather events. (5) *Small parks and neighbourhood activity spaces*, including pocket parks, playgrounds, and local recreation areas. (6) *Open spaces around the social housing complex*, including shared courtyards and residual uncovered areas. (7) *Streetscapes and roadside tree corridors*, with emphasis on tree densification, shading, and the continuity of green infrastructure. (8) *Roofs of apartment buildings and offices*, suitable for green roofs, solar installations, cooling measures, or communal uses. (9) *Uncovered spaces within apartment-building plots*, including internal courtyards, setbacks, and semi-private open areas. (10) *OSE railway infrastructure and station areas*, including the railway station building, platforms, and adjacent underused land. (11) *Church courtyards and associated open spaces*, where landscape improvements and climate-adaptive design could be introduced.

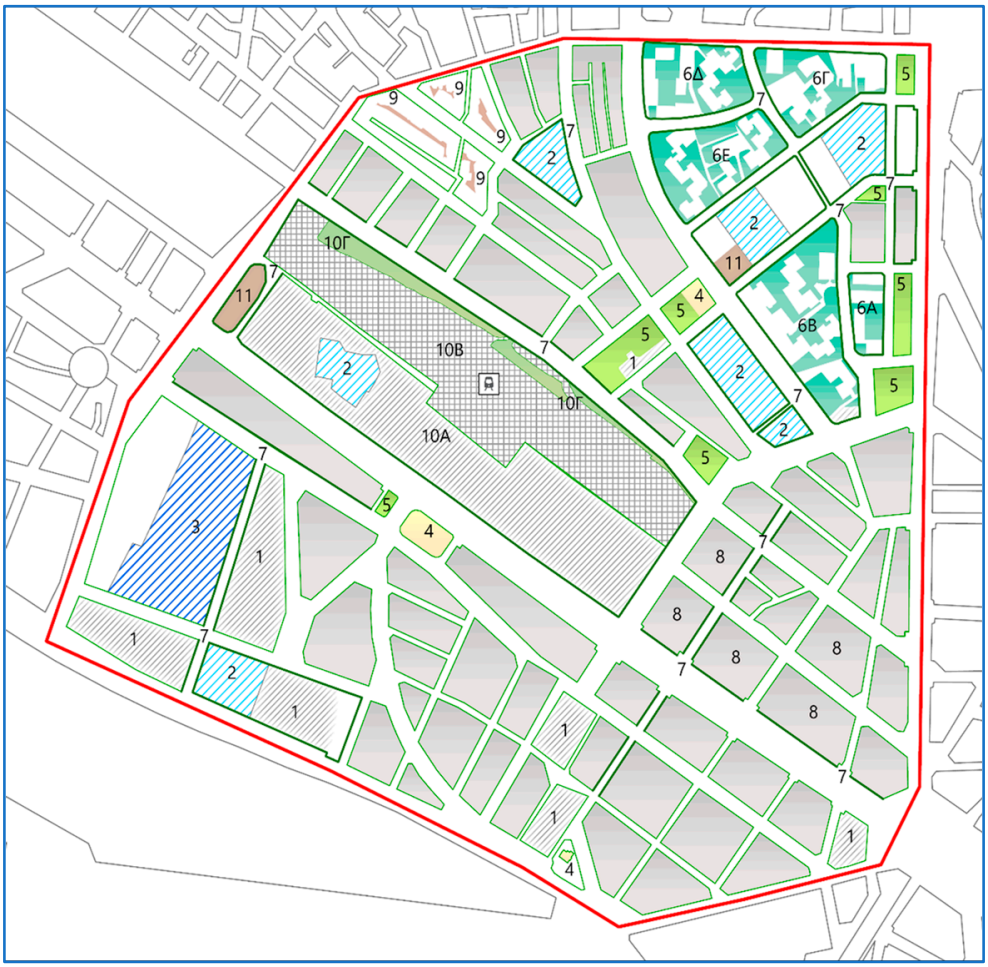


Figure 3. Map showing the 11 typologies of open spaces for renovation. Source: Panori et al. [6].

2.4. Methodological Approach

This study employs a case study research design that integrates a structured literature review, spatial analysis, stakeholder-informed intervention selection, and business model framework development, following an interpretivist, applied-analytical orientation consistent with emerging practice in urban NBS research and aimed at producing transferable insights for broader practice [25].

In the first analytical stage, a systematic spatial characterisation of the Railway District was conducted, synthesising land-use data, municipal planning documents, satellite imagery, and field observations. This mapping exercise, together with participatory engagement involving project partners, local stakeholders, and community members (ReGenWest Citizen Co-Lab), contributed to: (a) identifying eleven categories of open space (Section 2.3); (b) informing the selection of thirteen intervention types tailored to the area's urban morphology and ownership regimes; and (c) identifying/prioritising local needs and implementation priorities. The second stage comprised a structured review of the European NBS financing literature and established business model frameworks, focusing on EU-funded research initiatives such as Naturvation, Connecting Nature, NAIAD, and UNALAB and their associated toolkits and case databases. This review provided the conceptual foundation for the business model template applied in the third stage and enabled systematic benchmarking of CAPEX and OPEX parameters against comparable European projects. The grey literature—programme evaluations, municipal reports, and EU policy guidance—was integrated alongside peer-reviewed sources to capture practitioner knowledge relevant to the Greek institutional context.

The third stage was the core analytical contribution: the development and application of a structured business model template to each of the thirteen interventions. Adapted from the Connecting Nature Business Model Canvas [19] and the Naturvation NBS typology [22], the template organises each intervention around six analytical dimensions: (i) value proposition (environmental, social, and economic benefits generated); (ii) value creation and delivery (actors, mechanisms, and time horizons); (iii) value capture (how value is retained or monetised by specific stakeholders); (iv) financing model (CAPEX and OPEX structures and primary financing sources); (v) enablers (regulatory, institutional, or spatial conditions facilitating implementation); and (vi) barriers (structural, institutional, or financial constraints). The value-proposition dimension was further disaggregated into five ecosystem service clusters against which the primary (i.e., served by the intervention) and secondary (co-benefit) contributions of each intervention were derived qualitatively, based on the literature reviewed in the second stage. The same European benchmarking literature underpinned the CAPEX/OPEX ranges reported for each intervention.

The output of this template application produced a structured Business Model Card for each of the thirteen intervention types. The five categories of business models were subsequently derived (Section 3.4) through a qualitative synthesis of those cards using three primary grouping criteria: (i) dominant spatial context, (ii) ownership and control regime, and (iii) financing logic. These dimensions were considered jointly, as interventions with different technical characteristics may share a similar implementation configuration. Interventions presenting comparable configurations across these three criteria were grouped together. The remaining dimensions recorded in the cards, including, among others, value creation, value capture, common barriers and enablers, were then used to analyse and compare the resulting categories. The resulting Business Model Cards and synthesis analysis were subsequently reviewed by ReGenWest project partners, including representatives of the Municipality of Thessaloniki, the Thessaloniki Development Agency, and Aristotle University of Thessaloniki, as part of the project's internal review process. Figure 4 presents an illustrative card for the project category "Tree Planting" (see Section 3.2 for more details about this category).

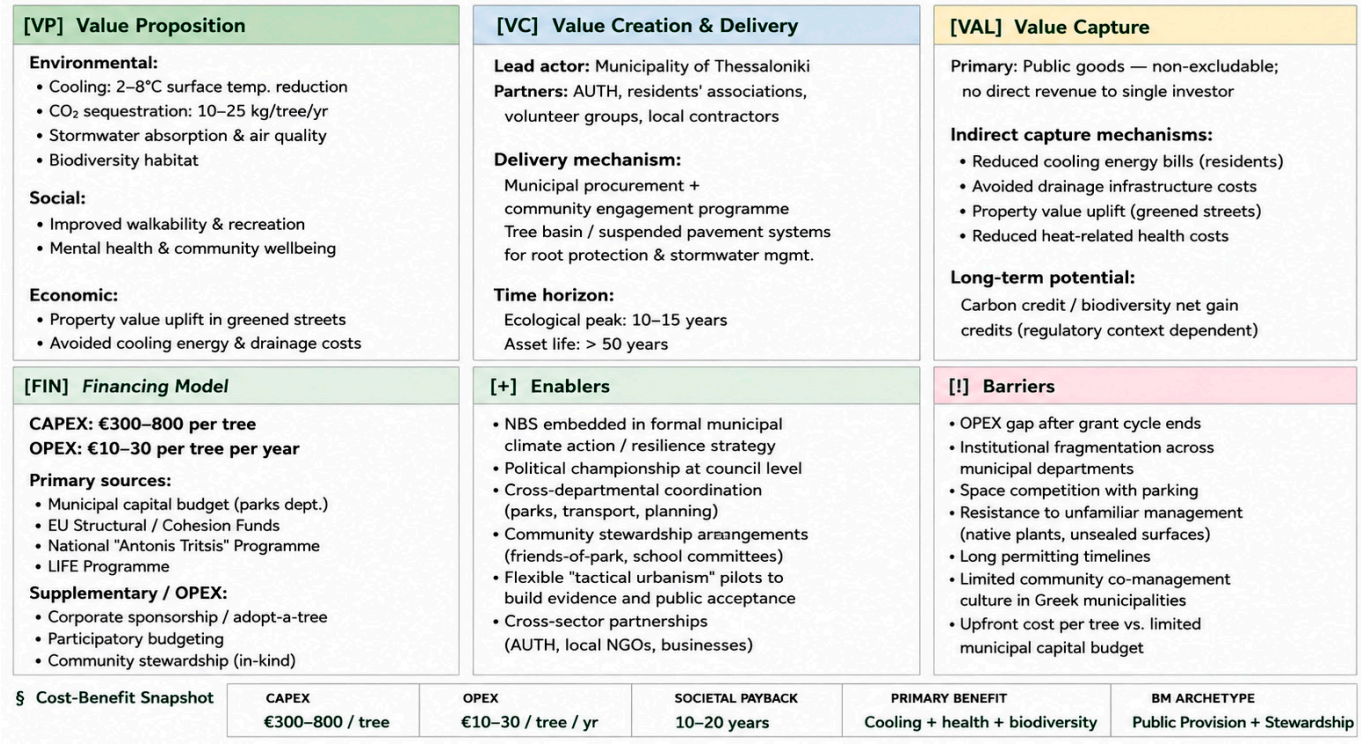


Figure 4. Illustrative Business Model Card for the project category "Tree Planting". Source: Authors, based on ReGenWest Deliverable A.4.2.4 (2026). Card template adapted from Toxopeus [22] and McQuaid [19].

3. Results: Business Models and Financing for Climate-Resilient Renovation

3.1. Design Principles and the Thirteen NBS Interventions

The renovation integrates city-planning principles from LEED for Neighbourhood Development (https://www.usgbc.org/leed/v5 accessed on 15 June 2026) with NBS-based CO_2 offsetting, RESs embedded in public infrastructure, and continuous monitoring, converging on two outputs: a "Master Plan for NBS and RES" and an "Environmental Monitoring System" (EMS) that documents its carbon-neutrality impact. The pilot is structured around three NetZeroCities-defined activities—(1) Mandate to Act: NBS for Carbon Neutrality, (2) Capacity to Act: NBS for Carbon Neutrality, and (3) Impact of NBS-RES on Carbon Neutrality—each beginning with a design iteration and feeding learning outcomes into the next, and anchored in Thessaloniki's 2030 Climate City Contract, focusing on two emissions domains: electricity (RES in public/shared spaces) and CO_2 sequestration (tree planting, green/blue space expansion). The EMS provides the digital infrastructure for registering, quality-checking, spatially mapping, and monitoring the proposed interventions. It integrates municipal, geospatial, satellite, historical, and citizen-generated data and, once the interventions are implemented, will present their progress and environmental performance through interactive maps, time-series dashboards, and quantitative indicators.

The design process identifies five challenges: co-designing with stakeholders to ensure solutions are socially acceptable, identifying the most effective interventions, managing resource-intensive and time-consuming implementation processes, developing co-funding business models able to attract public, private, and non-profit resources, and monitoring outcomes to guide iterative improvement. At the same time, four corresponding barriers are also highlighted: stakeholder fragmentation arising from the number of participants involved and their differing priorities, the complexity and red tape of city planning, the absence of established co-funding business models, and a lack of monitoring data for estab-

lishing baselines. Of these, the financing barrier is the central implementation challenge, and the motivation for the business model analysis that follows. Achieving carbon neutrality requires funding beyond public sources, and pioneering new co-funding arrangements for NBSs is the most pressing of the four barriers identified in the design process. This financing gap is what the business model framework developed in Section 3.2 is intended to address.

In the second design iteration, this framework was applied to select 13 project types (P1–P13) to drive the renovation of the 11 identified intervention areas (Figure 3). Each area was designed to be monitored through the EMS for energy generation, water retention, vegetation health, thermal comfort, and ecosystem value:

- *P1. Regreening/Green Areas:* Convert vacant lots and underused public spaces into green areas to address Western Thessaloniki's scarcity of quality green space and high share of impermeable surfaces.
- *P2. Tree Planting:* Densify street tree corridors and expand rootable soil volume, since much of the existing tree stock is constrained by impervious surfaces that limit root growth.
- *P3. Sustainable/Net-Zero Buildings*: Combine rooftop PV, green roofs, and reflective materials to upgrade a building stock characterised by ageing insulation and underused roof areas.
- *P4. Water Pockets/Rain Gardens*: Small-scale stormwater infrastructure to offset the area's high share of impervious surfaces and associated flood risk.
- *P5. Green Fences and Walls:* Vertical greening for space-constrained sites, prioritised on social-housing facades and at the AUTh Veterinary School, where degraded fencing is prevalent.
- *P6. Botanic Gardens*: Themed green spaces combining biodiversity and environmental-education functions, designed to link with tree planting and rain gardens into a coherent green network.
- *P7. Native Plants/Meadows:* Low-maintenance planting on vacant/degraded sites with existing semi-natural vegetation, supporting pollinators and stormwater infiltration.
- *P8. Bosco Verticale:* Façade- and balcony-level vegetation on existing apartment buildings, suitable for dense neighbourhoods with limited open land.
- *P9. Solar Canopy:* Photovoltaic (PV) structures over parking and public spaces, pairing energy generation with shade provision.
- *P10. Rooftop Solar:* PV structures on residential and public rooftops, many of which are currently unused, with potential to be combined with green roofs and to support energy communities.
- *P11. Smart Grid:* Neighbourhood-scale digital management of distributed generation, storage, and demand to integrate the PV interventions above.
- *P12. Permeable Pavements*: Replace sealed surfaces in parking and university areas to manage stormwater and reduce heat-island effects.
- *P13. High Reflective/Cool Materials*: Reflective surface materials for roofs and public spaces to reduce cooling demand and heat-island intensity, complementing P1–P12.

Table 1 maps the correspondence between the 11 intervention areas (A1–A11), implementation actors, and these 13 project types (P1–P13), reflecting priorities identified through participatory workshops with local stakeholders. This participatory selection process forms a key component of the overall design methodology.

Table 1. Correspondence between the 11 identified areas of intervention (A1–A11), the implementation actors, and the 13 proposed project types (P1–P13).

Areas	Implementing Actors	Project Types
A1. Empty plots & parking	Plot owners, municipality	P1. Regreening Design; P2. Tree Planting; P7. Native Plants/Meadows; P9. Solar Canopy; P12. Permeable Pavements
A2. Primary/Secondary education schools	Education authorities	P3. Sustainable Design; P4. Water pockets/Rain gardens; P10. Rooftop Solar
A3. Higher education facilities	Aristotle University of Thessaloniki	P4. Water pockets/Rain gardens; P5. Green Fences & Walls; P6. Botanic Gardens; P10. Rooftop Solar; P12. Permeable Pavements
A4. Urban squares redesign	Municipality of Thessaloniki	P1. Regreening Design; P2. Tree Planting; P4. Water pockets/Rain gardens; P9. Solar Canopy; P12. Permeable Pavements; P13. High reflective/cool materials
A5. Small-scale parks	Municipality of Thessaloniki	P1. Regreening Design; P2. Tree Planting; P4. Water pockets/Rain gardens; P7. Native Plant/Meadows
A6. Uncovered areas of social housing	Municipality of Thessaloniki plot owners	P2. Tree Planting; P5. Green Fences & Walls; P7. Native Plant/Meadows; P9. Solar Canopy; P12. Permeable Pavements
A7. Street-side tree corridors—green fingers	Municipality of Thessaloniki	P2. Tree Planting
A8. Building block rooftops	Building & plot owners	P3. Sustainable/Net-Zero Buildings; P8. Bosco Verticale; P9. Solar Canopy; P10. Rooftop Solar; P13. Highly Reflective/Cool Materials
A9. Uncovered spaces within building blocks	Plot owners	P1. Regreening Design; P2. Tree Planting; P5. Green Fences & Walls; P7. Native Plant/Meadows; P12. Permeable Pavements
A10. Train station complex	OSE	P1. Regreening Design; P2. Tree Planting; P3. Sustainable/Net-Zero Buildings; P5. Green Fences & Walls; P6. Botanic Gardens; P10. Rooftop Solar; P11. Smart Grid/Net-Zero Buildings; P12. Permeable Pavements
A11. Church courtyards	Churches	P2. Tree Planting; P4. Water pockets/Rain gardens; P5. Green Fences & Walls; P12. Permeable Pavements

Source: Authors' elaboration.

3.2. Benefits and Costs of NBS Interventions

The thirteen NBS interventions (project types) identified for the Railway District are likely to generate value across five principal ecosystem service clusters: (i) climate regulation and thermal comfort; (ii) hydrological regulation and flood risk reduction; (iii) biodiversity enhancement and ecological connectivity; (iv) energy production and carbon neutrality; and (v) social, health, and well-being benefits. Whether clusters are primary or secondary co-benefits depends on the design of each intervention. Technological interventions, for instance, tend to prioritise energy performance, while nature-based spaces more often treat social and public health value as core to their public-good case for investment [18,21]. Table 2 maps the primary and secondary contributions of each intervention across these five clusters.

Table 2. Ecosystem service contributions of ReGenWest NBS and RES interventions.

Intervention	Climate Reg. & Thermal Comfort	Hydrol. Reg. & Flood Risk	Biodiversity & Ecol. Connectivity	Energy Production & Carbon	Social, Health & Well-being
P1—Regreening/Green Areas	●	◐	◐	–	●
P2—Tree Planting	●	◐	◐	–	●
P3—Net-Zero Building Retrofits	◐	–	–	●	◐
P4—Water Pockets/Rain Gardens	◐	●	◐	–	◐
P5—Green Fences & Walls	●	◐	◐	–	◐
P6—Botanic Gardens	◐	–	●	–	●
P7—Native Plants/Meadows	◐	◐	●	–	◐
P8—Bosco Verticale	●	◐	◐	–	◐
P9—Solar Canopies	◐	–	–	●	◐
P10—Rooftop Solar PV	–	–	–	●	–
P11—Smart Grid	–	–	–	●	–
P12—Permeable Pavements	◐	●	–	–	–
P13—High-Reflective/Cool Materials	●	–	–	–	–

Note: ● = primary contribution; ◐ = secondary co-benefit; – = not applicable or negligible contribution. Source: Authors.

Climate regulation and thermal comfort are delivered most directly through tree planting (P2), regreening (P1), green walls (P5, P8), and highly reflective materials (P13). Empirical research across European climatic zones shows that such interventions can reduce surface temperatures by 2–8 °C in shaded areas relative to unshaded equivalents, with the precise magnitude depending on canopy density, urban morphology, and the intensity of the surrounding heat island [26,27]. In Mediterranean cities such as Thessaloniki, where summer surface temperatures on sealed surfaces routinely exceed 45 °C, this cooling effect delivers particularly high marginal returns by mitigating thermal stress where public health risks are most acute [28]. Hydrological regulation, by contrast, is the primary function of rain gardens (P4) and permeable pavements (P12): when properly designed, these features can retain 50–80% of annual runoff, significantly reducing peak stormwater flows into already strained municipal drainage networks [29].

Biodiversity enhancement is advanced principally through native meadows (P7) and botanic areas (P6), which provide habitats for diverse pollinator and bird communities. Street trees contribute a complementary carbon benefit, with a single mature tree sequestering an estimated 10–25 kg of CO_2 annually [30,31]. On the energy side, rooftop PV (P10) leverages the high-yield Mediterranean solar regime to generate 1300–1600 kWh/kWp per year, while deep building retrofits (P3) target demand reduction directly, cutting space heating and cooling requirements by 40–70% when structural envelope improvements are paired with upgraded HVAC (Heating, Ventilation and Air Conditioning) systems [32,33]. Social and public health benefits, such as thermal comfort, recreational use, and community cohesion, are delivered most broadly by publicly accessible green spaces (P1, P2, P6).

The co-production of multiple ecosystem services within single spatial interventions is a defining characteristic of the ReGenWest portfolio. The public Veterinary School courtyard in the study area (A3 in Table 1; typology 3 in Figure 3) exemplifies this approach, simultaneously targeting thermal comfort, stormwater management, energy generation, biodiversity, and social value. This multifunctionality strengthens the case for public investment by delivering benefits across multiple municipal policy domains, but it also introduces financial complexity by distributing value across a fragmented network of stakeholders who rarely coordinate spontaneously [18]. Addressing this coordination challenge is one of the main challenges that the business model framework developed in Section 3.4 is designed to address.

The cost structures of the thirteen interventions vary significantly in accordance with their technical complexity, scale, and spatial typology, as summarised in Table 3. CAPEX ranges from minimal incremental costs for high-reflective materials (€3–8/m^2) and native meadow planting (€1–3/m^2; in small, designed meadows prices may be quite higher) to substantial upfront investments for net-zero building retrofits (€500–1150/m^2) and solar canopy structures (€1000–2300/kWp). Intermediate CAPEX ranges apply to regreening and rain garden interventions (€100–350/m^2) and to tree planting (€300–800/tree). OPEX similarly varies: most nature-based interventions require annual maintenance in the range of €5–50/m^2 or €10–30/tree, while renewable energy systems carry low annual OPEX relative to their initial capital cost.

Table 3. Indicative CAPEX and OPEX ranges for the 13 interventions.

Intervention	Indicative CAPEX	Indicative OPEX	Principal Benchmarking Sources
P1—Regreening/Green Areas	€120–350/m^2	€20–50/m^2/yr	[34–36]
P2—Tree Planting	€300–800/tree	€10–30/tree/yr	[30,35]
P3—Net-Zero Building Retrofits	€500–1150/m^2	€5–10/m^2/yr	[37–39]
P4—Water Pockets/Rain Gardens	€100–250/m^2	€10–30/m^2/yr Site-specific (indicative O&M estimated as % of CAPEX)	[40,41]
P5—Green Fences & Walls	€80–1000/m^2	€5–15/m^2/yr	[35,42,43]
P6—Botanic Gardens	€40–150/m^2	€3–10/m^2/yr	[34,44]
P7—Native Plants/Meadows	€1–3/m^2	very low and site-specific	[43,45]
P8—Bosco Verticale	€20–300/m^2	€2–5/m^2/yr	[42,43]
P9—Solar Canopies	€1000–2300/kWp	€20–30/kWp/yr	[32,33,46]
P10—Rooftop Solar PV	€900–1400/kWp	€10–20/kWp/yr	[32,33]
P11—Smart Grid	Variable (system-scale)	Operational	No fixed unit-cost benchmark
P12—Permeable Pavements	€50–120/m^2	€1–5/m^2/yr	[40,41,47]
P13—High-Reflective/Cool Materials	€3–8/m^2 (incremental)	Minimal incremental	[48]

Notes: CAPEX = capital expenditure; OPEX = annual operational expenditure. Cost ranges are indicative benchmarks from the European literature.

A critical characteristic of the portfolio is the temporal asymmetry between CAPEX and OPEX financing accessibility. Capital costs are generally the most straightforward phase to fund through public grants and EU instruments, whereas OPEX presents a persistent structural challenge: once initial project grants are exhausted, ongoing maintenance costs frequently exceed the capacity of municipal budgets, creating a risk of ecological decline that undermines the long-term delivery of ecosystem services. This CAPEX-OPEX gap is identified throughout the European NBS literature as the principal structural vulnerability in urban NBS financing [19,20] and is equally relevant in the Thessaloniki context.

The cost figures provided in Table 3 should be interpreted as indicative European benchmarks rather than detailed engineering cost estimates for implementation in Thessaloniki. They primarily illustrate the different cost structures and financing requirements of RES and NBS interventions, both in terms of initial capital expenditure and recurring operation and maintenance costs. No uniform adjustment to Thessaloniki-

specific prices was applied, given the heterogeneity of the interventions and the underlying source data. Actual implementation costs may vary according to local labour and material costs, maintenance practices, procurement arrangements, institutional conditions, and market environments.

Moreover, financial feasibility also depends on factors extending beyond CAPEX and OPEX. The allocation of NBSs and RESs across individual intervention areas should also account for factors such as asset depreciation and lifecycle, economies of scale, user and stakeholder preferences, available surface area, structural load constraints on buildings, energy-generation potential, and the environmental performance of alternative configurations. These parameters can be incorporated into a common optimisation framework to examine alternative combinations of RES and NBS and identify feasible or preferred allocations for specific intervention areas. Such an approach has been developed for the ReGenWest case, where interactive multi-criteria optimisation and exhaustive search are used to explore alternative allocations of renewable energy and nature-based interventions for urban carbon neutrality [49].

3.3. From Interventions to Business Models: The Five Business Model Categories

The thirteen ReGenWest interventions are organized into five business model categories, reflecting their dominant spatial context, ownership regime, and financing logic. This grouping allows interventions with similar value creation and capture dynamics to be analysed together, revealing systemic patterns that would be obscured by intervention-by-intervention analysis. Each category is characterised by a distinct combination of primary financing sources, key actors, principal barriers, and enabling conditions, as outlined in the framework presented in Figure 4. Table 4 further details these category-specific profiles of the five business models.

BM_1: Public Space Interventions

The first category brings together interventions deployed primarily in publicly accessible spaces: regreening and green area creation (P1), tree planting (P2), water pockets and rain gardens (P4), botanic gardens (P6), and native plant meadows (P7). These interventions share a common financing logic grounded in the public-good character of their benefits (e.g., cooling, recreation, biodiversity, social cohesion, etc.) that accrues broadly across the urban population but usually does not generate a direct revenue stream for a single investor. CAPEX ranges from a few euros per m^2 for native meadow planting to €120–350/m^2 for fuller regreening schemes, while OPEX typically falls between €10–30 per tree and €20–50/m^2 annually for the larger green-area interventions. These place BM_1 within a public provision model, drawing primarily on municipal capital budgets, EU structural and cohesion funds, national grant programmes (e.g., Antonis Tritsis programme), and, in some cases, participatory budgeting or corporate park sponsorship motivated by CSR considerations.

Long-term maintenance represents the persistent weak point of BM_1 interventions. Specifically, capital investment via EU or national grants does not automatically translate into stable operational funding, and the gap between well-designed new green infrastructure and sustained ecological functioning is frequent, with publicly financed NBSs often underperforming or failing [18,50]. Community stewardship arrangements (e.g., friends-of-park groups, school maintenance committees, local volunteer networks, etc.) can supplement municipal operational capacity, but their longevity depends on continued engagement. It should be noted that this kind of arrangement is difficult to institutionalise, especially in Greece, where community co-management cultures remain comparatively underdeveloped (though emerging participatory budgeting pilots and adopt-a-tree schemes point to a growing civic appetite for co-governance).

Table 4. Business model categories: key characteristics, financing sources, actors, barriers and enablers.

BM Category/ Interventions	Primary Financing Sources	Key Actors	Main Barrier(s)	Key Enabler(s)	BM Archetype
BM_1 Public Space P1, P2, P4, P6, P7	Municipal budget, EU structural funds, LIFE program, "Antonis Tritsis" program, CSR/sponsorship	Municipality, EU/national agencies, community groups, NGOs	OPEX gap after grant cycle, institutional fragmentation, space competition	Political championship, formal NBS strategy, cross-sector partnerships, community stewardship	Public provision
BM_2 Private Space P5, P8	Private owner investment, national/municipal subsidies, preferential bank loans	Building owners, developers, municipality (catalytic), banks	Long payback horizons, split incentive (owner vs. tenant), limited financing culture	Facade greening subsidies, simplified permitting, green building certification, demonstration projects	Private market
BM_3 Hybrid P12, P13	Municipal CAPEX, private via regulatory mandate, development impact fees	Municipality, private developers, building owners, contractors	Misaligned incentives, limited regulatory standards, low lifecycle cost awareness	Piggyback NBS into routine maintenance, building code mandates, urban offsetting mechanisms	Public–private hybrid
BM_4 Multi-Tenant P3	"Exoikonomo" grants, preferential bank loans, EU Recovery Funds, ESCO models	Homeowners' associations, national government, banks/ESCOs	Collective action/split incentive, high upfront CAPEX, multi-owner complexity	State subsidy programmes, one-stop advisory services, regulatory clarity on collective borrowing	Public–community hybrid
BM_5 RES P9, P10, P11	Owner self-financing, commercial bank loans, net-billing savings, energy communities	Municipality, private owners, energy communities, banks, grid operators	High CAPEX for canopy structures, grid constraints, regulatory uncertainty	Energy community framework, combined solar + renovation financing, stable net-billing/metering policy	Private market/community

Source: Authors. ESCO = Energy Service Company; CSR = corporate social responsibility; Exoikonomo = Greek state-sponsored subsidy programs designed to help households improve the energy efficiency of their homes; Antonis Tritsis programme = Greek national public investment scheme that provides municipalities and regional authorities with funding for local infrastructure, environmental protection, and digital transformation.

Barriers extend beyond finance to include institutional fragmentation, as public space interventions frequently span multiple municipal departments, limited social acceptance for departures from conventional green aesthetics (urban meadows, for instance, may be perceived as unkempt by residents accustomed to manicured parkland), and competition with other land uses (parking plots seem to be the most competitive use in Thessaloniki). Political and policy embedding is the decisive enabling condition: cities that have integrated NBSs into formal climate action or resilience strategies achieve demonstrably higher implementation rates, as this alignment justifies budget allocation and provides institutional legitimacy for cross-departmental coordination [18,51].

BM_2: Private Space Interventions

The second BM category covers interventions implemented on privately owned surfaces such as green fences and walls (P5) and Bosco Verticale-type vertical greening systems (P8). The business logic differs fundamentally from that of BM_1. Namely, while these interventions also generate important urban co-benefits (microclimate regulation, aesthetic

improvement, stormwater management), their implementation mainly depends on private owner initiatives and is primarily justified by indirect economic returns/benefits such as (i) reduced cooling energy costs, (ii) increased property values and rental attractiveness, (iii) enhanced building marketability, and, in some regulatory contexts, (iv) compliance with green building standards.

Direct revenue generation is uncommon, and the business case rests on cost avoidance and value enhancement over medium- to long-term horizons. Payback periods for engineered living wall systems (indicative CAPEX of €400–1000/m^2) are typically long and depend on energy price assumptions that many owners, particularly smaller landlords with limited capital, are reluctant to internalise. Split-incentive problems further constrain adoption in multi-tenant buildings, where installation costs fall on owners while energy savings accrue to tenants [42]. Public policy plays an enabling but catalytic role here: subsidies for façade greening, simplified permitting, and green building certification can materially improve the cost–benefit balance and accelerate private adoption. To protect the continuity of publicly supported interventions when a property changes ownership, subsidy and permitting arrangements may also include property-linked maintenance requirements that remain applicable to subsequent owners, where legally feasible.

BM_3: Public–Private Hybrid Interventions

The third category comprises interventions like permeable pavements (P12) and highly reflective and cool materials (P13) that can be deployed across both public and private spaces, with costs and benefits distributed across multiple actor types. These interventions follow a hybrid financing logic in which public investment addresses municipal assets while private expenditure is mobilised through regulatory requirements and targeted incentives. CAPEX is comparatively modest: €50–120/m^2 for permeable pavements and as little as €3–8/m^2 for highly reflective coatings applied as an incremental upgrade, with correspondingly low OPEX of €1–5/m^2/yr or less.

The key analytical insight for BM_3 is that the incremental cost of choosing a climate-adaptive option over a conventional one is often modest when the intervention is integrated into works that would occur regardless, such as street resurfacing, roofing replacement, and building renovation. The marginal additional cost of specifying a permeable rather than impermeable pavement or applying a high-albedo coating to a roof undergoing replacement is substantially lower than the standalone cost of the same intervention [20]. This creates a strategic "piggyback" financing logic, in which embedding NBS requirements into routine maintenance cycles reduces the effective cost burden on both public and private actors. The central barrier is misaligned incentives across property boundaries, compounded by limited familiarity with lifecycle cost advantages among civil engineers and building professionals, who often default to conventional grey solutions. Green factor requirements or mandatory minimum standards in building codes could improve the financing landscape for BM_3 interventions in the Greek context.

BM_4: Multi-Tenant Building Solutions

The fourth category covers comprehensive building-scale interventions in multi-owner or multi-tenant settings, such as sustainable and net-zero building retrofits (P3). These interventions are characterised by high upfront capital requirements (€500–1150/m^2) and comparatively low annual OPEX (€5–10/m^2/yr), but they combine long payback horizons and technical complexity with the need for collective decision-making among homeowners' associations, individual flat owners, and institutional building managers, whose interests and financial capacities may diverge significantly.

The value proposition of BM_4 is compelling across the full asset lifecycle. Deep retrofits can generate substantial energy cost savings, improve thermal comfort, increase

asset value, and reduce long-term exposure to climate-related risks. In the Greek context, however, the gap between these long-term benefits and the upfront investment required is particularly acute. This reflects both constrained access to private financing and the collective-action challenge of achieving homeowner consensus in multi-family apartment buildings, where decisions often depend on multiple owners with different priorities and financial capacities.

State-led subsidy programmes are the pivotal enabling mechanism. For example, the "Exoikonomo" programme, which provides grants and preferential loans for energy-efficiency renovations (funded through national and EU structural resources), has significantly improved the financial feasibility of deeper retrofits. Its implementation shows that targeted state subsidies/support can unlock/mobilise substantial private co-investment. District-scale adoption will require integrating this financial support with facilitation services, such as one-stop advisory mechanisms for homeowners' associations, together with demonstration projects that are likely to build trust in retrofit performance under Greek climatic and construction conditions.

BM_5: Renewable Energy Solutions

The fifth category encompasses solar canopies (P9) and rooftop PV installations (P10), which can also be coupled with smart grid infrastructure (P11) to enable their collective management. Compared to the preceding four NBS-centred categories, BM_5 follows a more conventional investment logic: solar PV directly offsets energy consumption costs, with significant initial CAPEX (€900–1400/kWp for rooftop PV; €1000–2300/kWp for solar canopies), low OPEX (€10–30/kWp/yr), and long asset lifetimes of 20–25 years that support financial planning through accumulated savings.

In Greece, BM_5 financing operates within a national regulatory framework that includes net-billing and virtual net-billing arrangements, collective self-consumption schemes, and energy community models enabled by the transposition of EU Directive 2018/2001. Net billing, including virtual net billing, is a self-consumption scheme in which electricity produced by a photovoltaic system is used to cover on-site or geographically dispersed consumption, while any surplus is exported to the grid and compensated at a market-based price. This differs from the previous net metering system, where each unit of electricity produced by the photovoltaic system could directly cancel out one unit of electricity consumed from the grid. At the residential and community scale, these structures allow groups of users to pool investment in shared solar installations and collectively manage self-consumption, opening BM_5 to households that cannot access individual rooftop solutions due to ownership fragmentation or capital limitations. The principal barriers are mainly structural, including, among others, high CAPEX for canopy structures, grid capacity constraints, administrative complexity, and regulatory uncertainty regarding the continuity of net-billing frameworks. Combining solar installations with complementary uses (for instance, integrating canopies with Electric Vehicle (EV) charging or linking rooftop PV with BM_4 building renovation) is likely to improve financial viability and broaden access to funding instruments.

Synthesis: Positioning the Five Categories

Taken together, the five categories capture the main financing and governance arrangements through which urban NBS and RES interventions can be implemented, from the heavily public-dependent BM_1 to the largely market-driven BM_5. Figure 5 maps this spread within the Pestoff Triangle [24], positioning each category according to the relative weight of state, market, and community actors in its financing and governance logic.

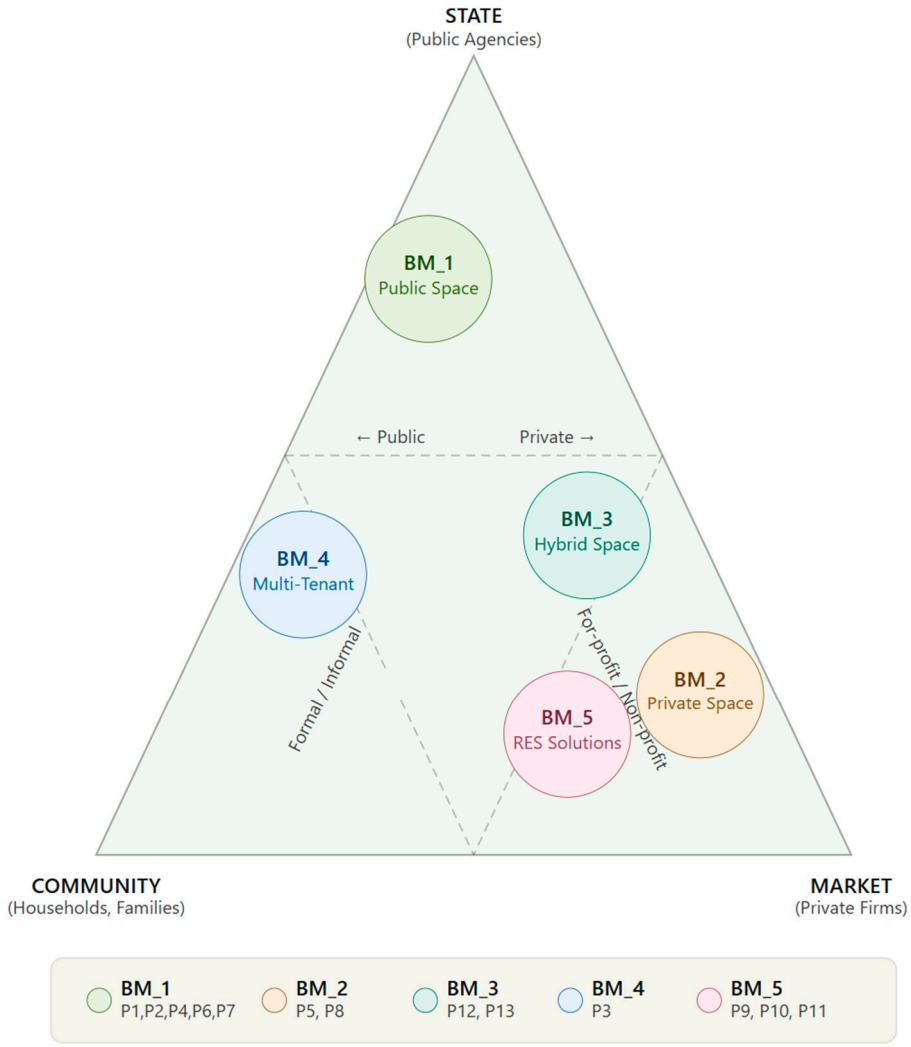


Figure 5. Positioning of ReGenWest business model categories within the Pestoff Triangle [24].

The placement of each category is deliberate, with BM_1 positioned closest to the STATE apex, reflecting its dependence on municipal budgets and EU grants, while its slight lean toward COMMUNITY captures the role of voluntary stewardship. BM_2 and BM_5 both gravitate toward MARKET, though BM_5 sits notably closer to COMMUNITY, reflecting the collective self-consumption structures that distinguish energy communities from purely market-driven investments. BM_3 occupies a central position between STATE and MARKET, consistent with its combination of direct public investment and policy-induced private expenditure. The most distinctive positioning is that of BM_4, which leans markedly toward COMMUNITY: this reflects the central role of homeowners' associations as the primary collective decision-making unit in Greek multi-family buildings and carries the policy implication that deep retrofits depend less on market mechanisms than on the capacity for collective action at the building level.

3.4. Local Financing Landscape: Opportunities and Structural Constraints

The analysis of business models across the five categories reveals a consistent structural pattern in the Thessaloniki context: the public sector—through municipal budgets, national grant programmes, and EU structural, cohesion, and recovery funds—remains the necessary backbone of NBS financing; yet, public funding alone is insufficient to ensure either the scale of implementation required for meaningful ecological impact or the long-

term operational sustainability of individual interventions. This pattern is characteristic of Southern and Eastern European cities more broadly [18,50].

In the Thessaloniki metropolitan area, significant EU grant resources are available through multiple channels: cohesion and structural funds administered via the Regional Operational Programme of Central Macedonia, specialised environmental funding through the LIFE programme, and innovation-oriented support through Horizon Europe. National instruments, including the "Recovery and Resilience Plan", the "Antonis Tritsis" sustainable urban development initiative, and the National Green Fund, and sector-specific programmes such as "Exoikonomo", further expand the financing palette. The scale of funding accessible when NBS proposals are effectively framed around EU and national policy priorities is illustrated by the neighbouring Pavlos Melas Municipality, which secured €10 million from the National Recovery and Resilience Plan to finance the first phase of a 33-hectare metropolitan park on a former military brownfield site [52].

The structural constraint on this otherwise substantial resource base is the temporal mismatch between capital grant cycles and operational continuity. Greek municipal budgets allocate limited resources for the ongoing maintenance of green infrastructure, and the cultural expectation that municipalities bear all costs of urban greening, without meaningful private or community co-financing, compounds this vulnerability. The result is a recurring pattern in which NBSs are successfully installed using project grant funding, only to decline in ecological functioning once external support ends—the OPEX gap that Figure 1 (Section 2.1) flags as the precondition for NBS value to appreciate rather than decline.

Addressing this maintenance gap requires a deliberate shift from project-based to institutionalised financing arrangements, including embedding NBS stewardship within routine municipal operations, regulatory frameworks applicable to private development, and community governance structures capable of sustaining engagement over time. Additional structural constraints include limited municipal borrowing capacity, rigid procurement rules, fragmented departmental responsibilities, and underdeveloped local markets for NBS-related services such as green infrastructure maintenance and community environmental management.

3.5. Towards Blended Financing: Combining Public, Private, and Community Resources

International best practice consistently identifies a blended financing strategy as the most robust approach to NBS financing, particularly for the operational phase where municipal budgets are most constrained. This strategy combines public grants, public budgets, private investment, and community resources. However, because the five business model categories differ in ownership structure and actor base, the optimal blend of instruments is not the same for each: what works for publicly owned green space is not necessarily transferable to privately owned facades or multi-tenant buildings. Table 5 maps the applicability of specific financing instruments across the five categories in the Thessaloniki institutional context, and the discussion below works through each category's specific blend in turn.

For BM_1 (public space interventions), the most promising blending arrangements combine EU and/or national grant funding for CAPEX with corporate park sponsorship and adopt-a-tree schemes for OPEX co-financing, supplemented by community stewardship arrangements that reduce the operational burden on municipal budgets. Precedents already exist in Thessaloniki, where banks and foundations have sponsored pocket parks and playgrounds, demonstrating that CSR-motivated private contributions are accessible when the public benefit is visible. Scaling these arrangements requires formalised institutional frameworks, such as park sponsorship contracts, community gardening agreements, or participatory budgeting mechanisms. These frameworks provide legal clarity and ensure continuity beyond the efforts of specific committed individuals.

Table 5. Applicability of financing instruments across the five business model categories.

Financing Instrument/Source	BM_1 Public	BM_2 Private	BM_3 Hybrid	BM_4 Multi-Tenant	BM_5 RES
A. Public grants & programmes					
Municipal capital budget	●	–	◐	–	◐
EU Structural/Cohesion Funds	●	–	◐	◐	◐
EU LIFE Programme	●	–	◐	–	–
National "Antonis Tritsis" programme	●	–	◐	–	–
National Recovery & Resilience Plan (NextGenEU)	◐	–	◐	◐	◐
"Exoikonomo" energy renovation subsidy	–	–	–	●	–
B. Private investment & market instruments					
Private owner self-financing	–	●	◐	◐	●
Commercial bank loans (standard)	–	◐	◐	◐	●
Preferential loans (state-backed)	–	◐	–	●	◐
Net-billing (or net-metering)/self-consumption savings	–	–	–	–	●
Energy community models	–	–	–	–	●
C. Blended & innovative instruments					
Corporate sponsorship/CSR/adopt-a-tree	◐	–	–	–	–
Participatory budgeting	◐	–	–	–	–
Development impact fees/planning gain	–	–	◐	–	–
Urban offsetting/biodiversity net gain funds	◐	–	◐	–	–
Green/sustainability-linked bonds	–	–	◐	–	◐
Community crowdfunding/stewardship (in-kind)	◐	–	–	–	–

Note: ● = primary/dominant financing source; ◐ = complementary or supplementary source; – = not applicable. Source: Authors, based on UNEP-CCC [20].

For BM_2 (private) and BM_3 (hybrid) interventions on private land, the key mechanism is regulatory co-financing. This means using public incentives to make private greening investments more attractive by lowering their costs and improving their risk-return profile. Planning gain instruments represent an underutilised tool in the Greek regulatory context. They can require developers to integrate NBSs on-site or contribute financially to nearby green infrastructure as part of the development approval process. Urban offsetting mechanisms, linking development impact fees to dedicated NBS investment funds, offer a further avenue for internalising the environmental costs of urban densification. Implementing these instruments would require updates to planning regulations, which are currently absent from Greek municipal practice but are well-established across Northern and Central European cities.

For BM_5 (renewable energy interventions), the energy community framework enabled by the transposition of EU Directive 2018/2001 represents a potentially transformative instrument for collective solar deployment in residential neighbourhoods. This framework may allow residents of adjacent buildings to pool investments in shared installations and distribute generated electricity among members. The Railway District, with its predominantly multi-family apartment buildings, presents favourable conditions for piloting such

models, particularly where solar canopy deployment over intra-block spaces can combine renewable energy generation with shading and comfort co-benefits.

4. Discussion

This study set out to address the implementation gap identified in the beginning of this paper: that NBS research has concentrated on ecological performance and technical design while paying considerably less attention to the institutional and financial conditions for implementation [14], and that existing financing studies remain fragmented, typically examining isolated instruments or case studies without systematically linking intervention types to business model configurations [17]. The results from the Railway District of Thessaloniki respond to this gap directly, but in a way that qualifies the value-capture argument set out in Section 2.1 rather than simply confirming it. The public-good framing, stating that NBS benefits are non-excludable and non-rival, and therefore structurally resistant to private financing [18,53], accurately describes BM_1 (public space interventions: regreening, tree planting, rain gardens, botanic gardens, native meadows), where benefits increase broadly with no direct revenue stream. It describes BM_4 and BM_5 (building retrofits and renewable energy) far less, since these generate appropriable returns, such as energy savings, avoided cooling costs, and asset value uplift, which make them tractable for market and household-level financing despite comparable or higher CAPEX. The value-capture problem, in other words, is real but intervention-specific rather than a general property of NBSs, which sharpens rather than overturns the conceptual starting point of the paper.

This intervention-specific pattern is the analytical basis for the paper's central contribution, as it enables the development of a spatially grounded typology linking ownership structure, scale, and stakeholder configuration to financing mechanism. Where the Naturvation catalogue [22] and the Connecting Nature Business Model Canvas [19] identify business model archetypes largely independent of spatial context, our results show that context is doing much of the explanatory work. The Pestoff Triangle positioning (Figure 5) makes this concrete: the five categories spread across the state–market–community space largely along ownership and stakeholder lines, with each category's position traceable to who controls the asset and who captures the value it generates rather than to its environmental function. BM_4 offers the clearest illustration of this framework: building retrofits are conventionally treated as private investment decisions, yet in the Greek multi-tenant context their adoption is governed by collective decision-making among homeowners' associations, pulling them toward community rather than market. This result extends Section 2.2's typology in a specific direction: the same retrofit intervention would plausibly sit closer to the market apex under a different ownership regime (e.g., single-owner buildings), which supports the paper's argument that business model selection is an outcome of institutional context layered onto intervention type, not a property of the intervention alone, directly addressing the fragmentation Raymond et al. [17] identify between intervention-level and business-model-level analysis.

The transferability of the proposed framework, therefore, lies less in replicating the analytical sequence that links intervention areas, intervention types, and business model configurations. In other urban contexts, the same NBS or RES intervention may correspond to a different business model depending on land and building ownership, stakeholder configuration, municipal fiscal capacity and the local regulatory environment. The framework can therefore be applied as a decision logic: cities may first identify relevant spatial intervention areas and feasible project types and subsequently determine appropriate financing and governance arrangements according to who controls the asset, who bears the costs and risks, and who captures the resulting value. Accordingly, the five business model

categories identified in the Railway District of Thessaloniki serve as context-dependent reference configurations whose applicability should be reassessed for each urban setting.

A second strand of the literature this study engages concerns the temporal structure of NBS value, developed conceptually through the CAPEX/OPEX asymmetry [19,20]. The evidence confirms this asymmetry empirically rather than merely illustrating it: CAPEX is comparatively accessible across all five categories through EU structural funds, the Recovery and Resilience Plan, and instruments such as Exoikonomo and the Antonis Tritsis programme, while OPEX remains the binding constraint once project grants expire. This is the mechanism by which Figure 1's appreciating-asset logic fails in practice: NBS value appreciates only if the Phase C stewardship gap is bridged, and the Greek institutional context—characterised by limited municipal borrowing capacity, rigid procurement, and an underdeveloped local market for green infrastructure maintenance—means it frequently is not. This is consistent with, and gives a Southern European institutional grounding to, the general CAPEX-OPEX vulnerability documented across the wider European NBS literature [19,20,51].

The BM_3 results surface a financing mechanism not explicit in the typologies reviewed in Section 2.2: a "piggyback" logic in which the incremental cost of a climate-adaptive specification (permeable over conventional paving, high-albedo over standard roofing) is small when bundled into capital-renewal cycles—resurfacing and roof replacement—that would occur regardless of any NBS objective. This complements rather than replicates the archetypes in Toxopeus [22] and Mayor et al. [18], as value capture here depends less on identifying a new revenue stream than on timing an intervention against an existing one, a pathway distinct from both the public-good logic of BM_1 and the market logic of BM_5.

These category-specific dynamics indicate that blended finance, which has long been identified as the most robust general response to the NBS financing gap [50–52], needs to be operationalised differently for each business model category, rather than applied as a single recipe, following the category-specific combinations already set out in Section 3.5 (Table 5). This is the practical expression of the business model perspective proposed as an alternative to a narrow financing-instrument view [16], where these are not simply funding combinations but governance arrangements distributing value among the specific stakeholders that each spatial and ownership context implicates, in line with the argument that the value-creation/value-capture mismatch is ultimately an institutional rather than a purely financial problem [15].

Finally, the barriers identified across categories, referring to institutional fragmentation, limited social acceptance of less-manicured green typologies, split incentives in multi-tenant buildings, regulatory gaps around planning-gain instruments, and administrative constraints on collective solar, are predominantly governance rather than financial in nature, echoing barriers documented across other European cities [52,54]. These reinforce the argument that governance complexity, not financial constraint alone, is what most often prevents NBS projects from progressing past the design stage [13]. This closes the loop on the paper's third contribution: financing innovation identified through the business model framework is necessary but not sufficient without governance arrangements, such as political embedding, institutionalised stewardship, and collective decision-making support, which are capable of sustaining the value NBSs create over their full, appreciating lifecycle.

5. Conclusions

NBSs have become central to climate-neutrality and urban regeneration strategies precisely because they generate environmental, social, and economic value simultaneously, but this multifunctionality is also what makes their financing difficult, since most of this value is public and collective rather than directly appropriable. This paper examined how

business models and financing arrangements can close this gap, using the Railway District of Thessaloniki and its thirteen NBS/RES interventions as a case study.

The analysis shows that NBS viability depends on aligning value creation, value capture, financing, and governance, and this alignment is intervention-specific, not uniform. Ownership structure and stakeholder configuration, together with the technical characteristics, determine which of the five business model categories (BM_1–BM_5) applies. This positions business models as integrative configurations that encompass financing strategies and governance arrangements, specifying how value, costs, risks, and responsibilities are distributed across the actors implicated by each spatial and ownership context. The institutional barriers identified across categories, including fragmentation, split incentives, and regulatory gaps, confirm that the implementation gap motivating this paper is institutional as much as financial. Several limitations qualify these conclusions. First, the analysis is based on a single case study district, and while the Railway District's mix of social housing, university facilities, and underused public space offers a reasonably diverse testbed, the CAPEX/OPEX figures, business model configurations, and Pestoff Triangle positions reported here are indicative but not generalisable to cities with different characteristics, such as ownership regimes, fiscal capacities, or planning systems. Second, the cost ranges underpinning Tables 2 and 3 are drawn from the European benchmark literature and not from realised local procurement or maintenance data, since the interventions have not yet been implemented; actual costs, and therefore the relative attractiveness of each business model, may diverge once construction and operation begin. Consequently, the framework does not formally model the ecological or socio-economic outcomes of the interventions themselves, which would require longitudinal monitoring data not yet available at this stage of the project.

Therefore, the theoretical contribution of this study should be understood primarily within the literature on district-scale carbon-neutral and climate-resilient urban transformation, rather than as an attempt to develop a new NBS business model theory. Using ReGenWest as an applied case study context, the framework examines how NBSs and RESs with different value profiles can be assembled within a common urban regeneration pathway. Within this perspective, RESs contribute directly to progress towards carbon neutrality and climate mitigation through local renewable energy production and the reduction in associated GHG emissions, whereas NBSs combine carbon-sequestration potential with climate-adaptation functions and wider environmental and social co-benefits, including thermal comfort, biodiversity, stormwater management, public health, and well-being. NBSs can also facilitate the spatial integration of energy infrastructure within a dense urban district. The conceptual contribution of the framework consequently lies in linking the financing, ownership, and governance of individual NBS and RES interventions to their differentiated but complementary functions within a district-level pathway towards carbon neutrality.

By linking intervention typology, ownership structure, and financing logic into a single spatially grounded framework, the study offers urban planners and policymakers a practical route from climate-neutrality strategies to implementable projects and extends the NBS business model literature beyond generic financing categories toward context-specific configurations. Future research will translate these business model configurations into project-specific financing roadmaps for selected interventions, specifying funding shares, implementation priorities, contractual responsibilities, and risk-allocation mechanisms according to site-level technical designs, ownership agreements, available financing programmes, and stakeholder commitments. Future research should also test these business models against real-world implementation outcomes, assess their long-term financial and ecological performance, and examine how emerging governance innovations can be scaled

beyond the Railway District. More broadly, the future scaling of NBSs will depend less on technical solutions, which are largely mature, than on cities' capacity to build the institutional and financing architecture this paper has begun to map.

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Abbreviations

The following abbreviations are used in this manuscript:

BM	Business Model
CAPEX	Capital Expenditure
CSR	Corporate Social Responsibility
EMS	Environmental Monitoring System
ESCO	Energy Service Company
EU	European Union
EV	Electric vehicle
HVAC	Heating, Ventilation, and Air Conditioning
NBS	Nature-Based Solution
LEED	Leadership in Energy and Environmental Design
OPEX	Operational Expenditure
RES	Renewable Energy Solution
PV	Photovoltaic

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