Urban Energy Redevelopment Projects: A Protocol for Economic and Financial Risk Assessment Under Public Incentive Policies

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Abstract. Growing urbanisation and energy efficiency challenges pose the need for innovative strategies to reduce the environmental impact of cities. This study proposes to address this need through the definition of a protocol to assess the financial and economic risk of urban energy redevelopment projects implemented through public incentives (tax breaks or public funding), focusing on the Italian context but with an approach that can be replicated internationally. The methodology is based on a critical analysis of the existing regulatory framework and the synthesis of international best practices. The protocol envisages eleven phases, including the preliminary analysis of the urban context, the identification of interventions, the evaluation of incentive policies, the study of the main criticalities characterising these policies and the analysis of the economic and financial risk in probabilistic terms. In the next phase of risk assessment, objective thresholds of risk tolerability and acceptability are defined using the ALARP principle, originally employed in industrial engineering to estimate the probability of loss of life. The final considerations highlight the importance of a holistic assessment of the risks and economic benefits associated with urban energy efficiency projects to ensure sustainable investments and maximise the results.

Keywords: Urban Energy Projects · Energy Urban Policy · Economic Evaluation of Projects · Economic Evaluation Protocol · Risk Assessment · ALARP Principle

1 Introduction

The transition to renewable and sustainable energy sources has become a global priority in the context of the urgent need to tackle climate change and reduce greenhouse gas emissions [1]. Despite significant progress on this issue, there has been a slowdown in the implementation of energy efficiency policies on a global scale since 2015. This has resulted in significant negative impacts on citizens, the environment and the land, to the extent that efficient protocols for assessing the economic and financial risk of intervention strategies in the energy sector are necessary [2]. After a ten-year low in 2020,

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which was recorded following the COVID-19 pandemic, global energy efficiency trends in 2021 were close to the previous average. However, economic growth has led to an energy demand that far exceeds the efforts made to curb energy consumption, reducing the rate of improvement of energy intensity (i.e. primary energy consumption per unit of gross internal product) to 1.7 per cent in 2017. This rate is the lowest recorded in almost five years [3]. Fortunately, according to the International Energy Agency's (IEA) report "Energy Efficiency 2022", the situation has improved by the end of 2022, as global investments in energy efficiency (including building renovation, public transport and electric car infrastructure) reached USD 560 billion, up 16% on 2021. Arguably, the global energy crisis triggered by the Russian invasion of Ukraine has stimulated a global response through policies, investments and public campaigns to promote energy efficiency. Among the most ambitious initiatives implemented in recent years at a global level in the field of energy efficiency, the aforementioned report mentions: the Inflation Reduction Act of the United States, the REPowerEU plan of the European Union, the Green Transformation (GX) programme of Japan, the Superbonus of Italy [4]. In addition to the above-mentioned measures, the European Union's (EU) recently revised Energy Performance of Buildings Directive (EPBD) is expected to further propel energy transition policies. The directive stipulates that by 2028 all new public buildings must be 'zero-emission', while by 2030 all new buildings, including non-public buildings, must reach this standard. Member states must define minimum energy performance requirements by 2030, and from the same year, the installation of photovoltaic solar panels on new public and non-residential buildings is mandatory. The entire European building stock must be 'zero-emission' by 2050 [5].

It is clear from the framework of reference that the combination of architecture and environmental sustainability has now assumed a crucial role in the definition of current energy policies. In the context of global challenges such as climate change and the progressive depletion of natural resources, the demand for energy-sustainable buildings is inexorably growing. This has stimulated the search for concrete and effective solutions in the field of green building, offering design solutions that are functional, environmentally sustainable and optimise the use of energy resources [6]. Green building aims to minimise the negative impacts on the environment and society resulting from the construction process and, at the same time, strives to improve the well-being of building inhabitants through a higher quality of life [7]. Furthermore, green redevelopment projects that include energy efficiency measures can generate a positive impact on the local economy by reducing operational costs and financial risks related to energy price fluctuations. What is more, such interventions can foster the competitiveness of investors and attract new ones, as well as optimise the value of assets through greater operational efficiency and a lower carbon footprint [8]. To pursue these aims, it is necessary to integrate green building practices with an approach to energy planning at urban and territorial levels that is more sustainable in socio-environmental and economic terms, thus connoting a multidisciplinary paradigm in the fields of architecture, town planning and urban appraisal. This paradigm is embodied in ways of planning urban environments and building design capable of minimising both greenhouse gas emissions and energy expenditure and consumption. This approach, through the implementation of innovative design strategies and the adoption of advanced technologies, aspires to create healthy

and sustainable living environments consistent with sustainable development goals [9]. Cities, regardless of their size, host a variety of facilities that support commercial, industrial, residential and community activities. Effectively addressing the energy needs of such facilities requires the implementation of targeted strategies and plans to balance energy supply and demand. Consequently, it is essential to develop energy policies that sustainably promote socio-economic development while ensuring the stability and prosperity of urban communities [10]. The convergence of sustainable building and urban energy planning issues with the economic evaluation of projects, especially with the economic and financial risk assessment of energy rehabilitation projects, is a crucial field of academic and scientific research. This integration requires an in-depth assessment of the economic and financial risks associated with energy rehabilitation measures, taking into account factors such as cost uncertainties, the instability of energy markets and the effectiveness of technologies. Appropriate models and methodologies need to be developed to manage these risks effectively, also considering the regulatory environment and collaboration between various stakeholders [11]. The approach to be adopted should therefore be integrated with the strategic legislative aspects of energy. Energy policies play a crucial role in supporting urban energy efficiency by providing financial incentives and tax breaks for energy upgrades of buildings and urban infrastructures [12]. These incentives stimulate the adoption of sustainable technologies and improve the economic sustainability of interventions by reducing initial costs and fostering the development of markets for innovative energy technologies. It is crucial to analyse the potential of these incentives to maximise both economic and socio-environmental benefits [13].

The goal of this work is to define a protocol for assessing the economic-financial risk relating to energy requalification interventions based on public energy policies applied in urban settings. The conceived protocol is divided into several key phases, including the preliminary analysis of the urban area subject to intervention, the identification and classification of the properties and infrastructures to be redeveloped, as well as the study of the tax breaks and financial incentives available. Subsequently, it involves the preparation of estimated metric calculations and project economic frameworks. Once the costs of the measures to mitigate the critical issues (of a technical, urban planning and administrative nature) potentially encountered have been defined, we proceed with the preparation of the forecast financial statement and the implementation of a cost–benefit analysis (CBA) for each type of intervention. This is followed by the risk analysis phase conducted via Monte Carlo simulation. The level of financial and/or economic risk of the interventions is then assessed through the introduction of objective thresholds of tolerability and acceptability of the risk borrowed from the theory on the ALARP (As Low As Reasonably Practicable) principle. The protocol, developed to evaluate the economic-financial risk of urban energy requalification operations, was conceived as an extension of another original protocol of the authors [14], which instead focuses on the economic-financial risk analysis to optimise the energy efficiency of individual buildings. Therefore, this study aims to broaden the evaluation scale from the building to the urban level. Although based on the Italian regulatory framework, the approach adopted is replicable and adaptable to other national contexts, thus providing a transferable methodological framework for the economic evaluation of urban energy redevelopment projects supported by public incentive policies. Another novelty consists in integrating

for the first time the ALARP approach to the risk analysis of projects at an urban planning level.

The work is structured as follows: Sect. 2 contains a brief review of the literature on the most recent applied research in urban energy redevelopment, an analysis of the main energy policies promoted internationally and in Italy, and a description of the ALARP principle; in Sect. 3 the economic and financial risk assessment protocol is presented and defined; finally, Sect. 4 reports a synthetic discussion, the main conclusions as well as future research ideas.

2 Literature Review and Regulatory Framework

For the definition of the aforementioned protocol, the preliminary analysis included both the latest applied research in the field of energy efficiency concerning various dimensions of the urban context (residential buildings, infrastructure and transportation, productive buildings, etc.), and the main energy policies based on public incentives and tax benefits, related to recent years, undertaken internationally and within the Italian context. Furthermore, the ALARP principle is examined, here integrated into the protocol to introduce objective thresholds of tolerability and acceptability of economic-financial risk.

2.1 Recent Research on Energy Efficiency in Urban Areas

Globally, multiple research studies have focused on analysing the economic and environmental effectiveness of smart urban infrastructures, including energy infrastructures [15]. Below are some more recent examples. Xia et al. (2021) analyse the work carried out on energy in smart city models and planning, dividing the methodologies into active and passive approaches and evaluating their implications on economic performance and energy security requirements for efficient management of resources [16]. Berardi et al. (2014) highlight the role of green roofs in promoting more sustainable buildings and cities, underlining the importance of efficient integration that considers climatic conditions and building characteristics. The study includes economic considerations on life cycle costs and global policies to support green roofs, demonstrating the environmental benefits and economic feasibility of this approach [17]. Huovila et al. (2019) analyse and compare 7 indicator standards for smart and sustainable cities (413 indicators), also focusing on the sectoral domains of energy and economy [18]. Talandier (2018) conducts an empirical investigation on 20 European cities involved in the energy transition, examining the correlations between different energy management approaches and the socio-demographic, economic, geographical and urban characteristics of these cities [19]. Jiang et al. (2022) propose the implementation of a new semi-supervised deep learning method that uses both labelled and unlabelled data, also of an economic nature, to improve the prediction of the energy use intensity of urban buildings [20]. Chang et al. (2020), selecting Beijing as the study city, propose four urban solid waste management scenarios, evaluating the reduction of landfills, energy recovery, life cycle costs and benefits, and greenhouse gas emissions. [21]. In the context of urban transport, Letnik

et al. (2018) develop a model for dynamic loading dock assignment for urban last-mile deliveries in energy-efficient and cost-effective ways [22].

From the literature analysis, a gap emerges regarding the analysis and evaluation of the economic and financial risk associated with tax incentive policies for urban energy efficiency.

2.2 International Energy Policies Based on Public Incentives and Tax Deductions

Tax incentive policies for urban energy efficiency have been widely adopted in several European countries such as Germany, France, Denmark, Greece, Belgium and the Netherlands [23]. These policies include the use of tax credits and tax breaks for the purchase of high-energy performance equipment and systems or for the implementation of energy retrofit interventions. However, there are significant differences in the approach adopted by each country, with some actively encouraging energy efficiency in homes through tax breaks, while others go so far as to implement measures that, paradoxically, discourage such interventions. For example, in Sweden, property tax is higher for buildings with excellent energy performance. Otherwise, in the Czech Republic, there is a tax break for those who replace the home heating system. Similarly, in Bulgaria, there is an exemption from property tax for energy-efficient buildings [24]. In other contexts, such as in Spain, grants and loans have been used to incentivize the renovation of existing buildings, but fiscal policy has not significantly contributed to the energy efficiency of the construction sector [25]. In the United States, tax credits for residential energy efficiency have been provided for several years, but have generated concerns regarding their equitable distribution and the possibility of excluding the most vulnerable segments of the population [26]. In Africa there is a lack of reliable energy data, hindering the implementation of sustainable energy policies. In Asia, several policies aimed at energy transition have recently been implemented in various sectors, including residential, but they often lack adequate regulation and are therefore fragmented [27, 28].

2.3 Italian Energy Policies Based on Public Incentives and Tax Deductions

In the Italian context, in recent decades, building bonuses have been implemented as an economic policy tool, with particular attention to energy consumption and seismic safety. These benefits are aimed not only at interventions on properties for residential use but also at works on properties intended for production purposes, owned by both citizens and legal entities. This expansion of tax breaks aims to promote interventions aimed at the modernization and renovation of the existing building stock, thus contributing to the sustainable development of the real estate sector [29]. The tax bonuses currently in force regarding energy efficiency interventions are as follows:

- Renovation Bonus (or Building Bonus): regulated by article 16-bis of Presidential Decree 917/86 (Consolidated Law on Income Taxes - TUIR), it offers a tax deduction of 36% of expenses incurred, without expiry, up to 48,000 euros per property. However, thanks to the special regime extended by the 2022 Budget Law, for expenses up to 31 December 2024, the benefit is 50% with a maximum limit of 96,000 euros. From 1 January 2025, unless extended, the deduction will return to 36% with a maximum

ceiling of 48,000 euros. However, the benefit does not extend to properties considered as capital goods (land registry categories: B – properties with public functions; C – properties of a commercial nature or appurtenances; D – commercial properties of a special type or properties with industrial; E – properties of collective interest; A/10 – private studios and offices) or as merchandise goods (properties towards the construction or sale of which the company activity is directed). Among the various interventions envisaged, it also includes those carried out to achieve energy savings (even if the 65% Ecobonus is more convenient for this type of intervention);

- Ecobonus: offers a 50% or 65% tax deduction, as long as the building is pre-existing and not new. The 50% deduction is applicable for the purchase and installation of fixtures, solar shading, front doors and external doors, as well as for the replacement of winter air conditioning systems with condensing boilers or biomass heat generators. The other possible types of energy interventions benefit from a 65% deduction. For condominium works, the deduction can vary from 70 to 85%. In any case, the spending ceiling depends on the type of intervention. This relief extends to buildings of any cadastral category, including instrumental ones. Eligible entities include natural persons and various forms of companies, including partnerships and corporations. It is possible to intervene on merchandise goods, capital goods and residential property, and there is the possibility of transferring the credit or obtaining a discount on the invoice;
- Superbonus: the measure was introduced in 2020 to promote energy efficiency and the reduction of seismic risks in buildings. Born with a percentage of 110%, in 2023 the measure dropped to 90%. In 2024 the benefit was further reduced to 70% for most cases, and will drop to 65% in 2025 and then end at the end of the year. From February 2023, only the tax deduction is permitted and no longer the possibility of requesting the transfer of credit or the discount on the invoice (opportunities currently reserved only for a small number of subjects). From 2024, the Superbonus can no longer be used for single-family buildings. Instead, condominiums and natural persons who own properties with 2 to 4 distinctly registered property units benefit from the 70% tax relief. Third-sector bodies will continue to benefit from the 110% relief until the end of 2025 (ONLUS – Non-Profit Organizations of Social Utility; OdV – Volunteer Organisations; APS – Social Promotion Associations). In this case, the properties must fall into the following cadastral categories: B/1 – colleges, boarding schools, shelters, orphanages, hospices, convents, seminaries and barracks; B/2 – non-profit nursing homes and hospitals; D/4 – for-profit nursing homes and hospitals. To have access to tax relief, the buildings subject to the works must achieve an improvement of at least 2 energy classes;
- Facade Bonus: extended until 31 December 2024 with a 90% deduction of expenses incurred, it is one of the most interesting tax breaks for those who want to renovate the exterior of their property. Among the works admitted, many of them contribute to the energy efficiency of the external building envelope (renovation of the thermal insulation, replacement of fixtures and doors, installation of solar shading). Properties of any cadastral category, including capital ones, can benefit from the deduction. It can be requested by natural and legal persons, as well as by both public and private entities. To obtain the bonus the property must fall within zones A and B according to Ministerial Decree 1444/1968;

- Green Bonus: also extended until 31 December 2024, it consists of a deduction of 36% of the expenses incurred for interventions relating to: greenery of private uncovered areas, appurtenances or fences, construction of irrigation systems, construction of wells, construction of hanging gardens and green roofs. These interventions can indirectly impact, even if minimally, energy efficiency. The properties must not fall into the categories of capital or merchandise goods. It follows that the bonus concerns only residential property [14, 30].

Table 1. Types of tax relief and public financing provided in Italy differentiated by intended use (deduction percentages valid for the year 2024)

Type of subsidy or financing	Deduction	Residential property	Productive property	Commercial property	Property and infrastructure of collective interest
Building Bonus	50%	✓	-	-	-
Ecobonus	50% o 65%	✓	✓	✓	✓
Superbonus	70% o 110%[a]	✓[b]	-	-	✓[c]
Facade Bonus	90%	✓	✓	✓	✓[d]
Green Bonus	36%	✓	-	-	-
State or European funding	-	✓[e]	✓	✓	✓

[a] 110% deduction valid only for Third-Sector entities.
[b] Only for condominiums and natural persons who own properties with 2 to 4 real estate units.
[c] Only for cadastral categories B/1, B/2 and D/4 belonging to Third-Sector entities.
[d] The property must be in Zone A or Zone B (Ministerial Decree 1444/1968).
[e] Financing mainly for public housing.

Energy efficiency measures for buildings and public infrastructures can be financed and incentivized through various methods. For example, the European Union makes financing and incentives available for energy efficiency projects through various programs and initiatives, such as the European Regional Development Fund (ERDF), the European Investment Fund Strategic Funds (EFSI), the Cohesion Fund (CF), the European Agricultural Fund for Rural Development (EAFRD), the European Maritime and Fisheries Fund (EMFF), the URBACT program (to promote sustainable urban development), etc. [31]. Also, the National Recovery and Resilience Plan (PNRR) includes significant investments to improve energy efficiency. In particular, through Measure 1 of Mission 2/Component 3 (M2C3) the PNRR proposes the implementation of a program to improve the efficiency and safety of the public building heritage, with interventions concerning particular schools and judicial citadels. Instead, investment 1.2 (Promotion of renewables for energy communities and self-consumption) of Mission 2/Component

2 (M2C2), aims to provide support to energy communities, in particular to municipalities with fewer than 5,000 inhabitants, to allow the installation of at least 2,000 MW of additional capacity from renewable sources, for an indicative production of 2,500 GWh/year, coupled with energy storage systems [32].

Table 1 summarizes the main forms of tax relief and public financing differentiated by intended use (residential, commercial, productive and of collective interest).

2.4 The ALARP Principle

According to the ALARP principle, when making safety and health decisions, risks must be reduced to the lowest level reasonably practicable [33]. Further risk reductions would be prohibitively expensive. This principle, already outlined in the UK Health and Safety Executive (HSE) regulations, is of crucial importance in contexts where it is necessary to balance risks, costs and potential benefits [34]. The ALARP principle recognizes that zero risk is not practicable, and introduces risk tolerability and acceptability thresholds. The lack of specific numerical values suggests the need to calibrate the model: for instance, the HSE recommends a "broadly acceptable" threshold of 10–6 deaths per year. The ICAF represents the cost of an investment to avoid one death and is calculated as the ratio between the cost of the investment and the expected reduction in the number of deaths. The risk is considered tolerable if the additional costs to further reduce it would be excessive, based on the comparison between the estimated ICAF and the reference values. Risks above the tolerability threshold must be reduced as they are considered unacceptable, while those between the tolerability and acceptability levels fall within the ALARP area and require mitigation measures up to a reasonably practicable level. Risks below the acceptability threshold are considered "largely acceptable" and do not require further mitigation measures. These criteria, commonly applied in high-risk sectors such as industrial engineering, mean that managers must reduce risks to the lowest levels reasonably possible, recognizing that beyond a certain point, further reductions always become more expensive [35, 36]. La logica ALARP è sintetizzata in Fig. 1. The ALARP logic is summarized in Fig. 2.

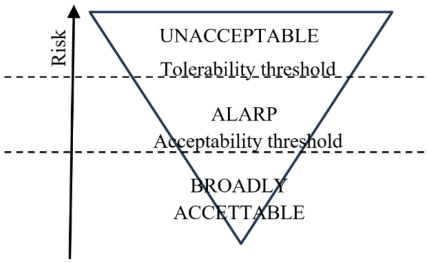

Fig. 1. The ALARP principle (own reworking from [14])

Recently, the ALARP approach has been applied in an original way, to evaluate the risk of financial failure of investment projects instead of the risk of loss of human life [37, 38]. In this work, the ALARP approach is integrated for the first time into an

original risk assessment protocol to define tolerability and acceptability thresholds of the economic-financial risk of urban energy redevelopment projects.

3 The Protocol

This section presents the economic and financial risk assessment protocol relating to energy requalification interventions that can be implemented through public energy policies applied in urban areas. The logical-sequential steps of the protocol are summarized in Fig. 2.

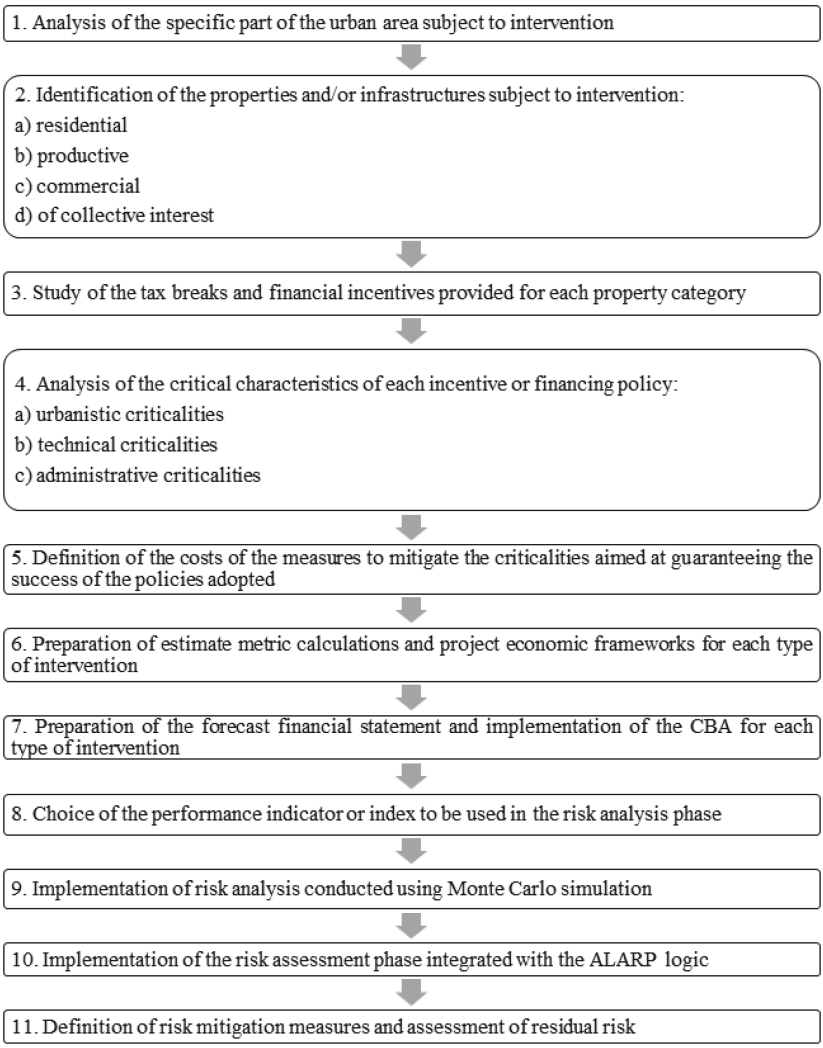

Fig. 2. Flowchart representative of the protocol steps

The following subsections describe the various logical steps in detail.

Phase 1. Analysis of the specific part of the urban area subject to intervention. In this phase, a detailed examination of the urban area designated for the building or urban planning intervention is carried out. This analysis includes the evaluation of the physical, environmental, socio-economic and urban characteristics of the area. Data relating to the structure of buildings, energy consumption, population density, existing infrastructure and any regulatory or environmental constraints are examined. The objective is to fully understand the specific context in which the intervention is inserted, identifying the opportunities and challenges that could influence the planning and implementation of energy efficiency measures.

Phase 2. Identification of the properties and/or infrastructures subject to intervention. This phase consists of specifically identifying the properties and/or infrastructures within the selected urban area subject to intervention. If the works involve multiple properties, it is essential to classify them based on their intended use (residential, commercial, productive, properties of collective interest). This categorization facilitates the management and planning of interventions, allowing a more detailed assessment of the needs and specific characteristics of each type of property or infrastructure.

Phase 3. Study of the benefits and financial incentives provided for each property category. This phase involves the study of the tax breaks and financial incentives available for each category of property identified in the previous phase. This process involves a detailed analysis of the tax regulations and financial incentive policies applicable to residential, productive, and commercial properties and infrastructures of collective interest. Tax credits, subsidized loans, grants and other incentives offered by public authorities or private institutions to promote energy requalification interventions are examined. The objective is to identify and evaluate the financing opportunities available to support energy efficiency interventions in each category of property, to maximize the economic benefits and incentivize the implementation of the interventions themselves.

Phase 4. Analysis of the critical issues characterizing each incentive/financing policy. This phase of the protocol concerns the analysis of the criticalities that characterize each incentive or financing policy, divided into three categories: urbanistic, technical and administrative criticalities.

- Urbanistic criticalities: to obtain funding or the benefits of building bonuses, buildings often must comply with state and local building and zoning regulations. Noncompliance leads to the loss of tax benefits and may be subject to severe sanctions and blocking of ongoing construction activities;
- Technical criticalities: these critical issues occur when the project requirements are not satisfied and the costs incurred are not considered appropriate. To access the Ecobonus, it is essential to present two crucial documents: the energy performance certificate, which describes the pre-intervention state and certifies the post-intervention energy improvement, issued by a qualified technician; the technical certification, transmitted exclusively electronically to ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development). In the case of the

Superbonus, these two documents must demonstrate an improvement in at least two energy classes;

- Administrative criticalities: concern the bureaucratic procedures and regulatory compliance necessary to access the available incentives and financing. These issues can include extended wait times, complexity of the required documents and burdensome administrative requirements. It is necessary to issue a certificate of conformity of the data relating to the documentation which certifies the existence of the conditions to benefit from the relief. Only professionals authorized to electronically transmit the tax return, such as accountants, commercial experts or employment consultants, are authorized to issue this certificate [14].

Phase 5. Definition of the costs of criticality mitigation measures. This phase involves the analysis and estimate of the costs necessary to address the critical issues identified during the previous phases of the evaluation process. These costs, which represent with good approximation a quantitative measure of the three critical issues (i.e. the risks associated with the interventions), will be used as sensitive variables in the subsequent risk analysis phase. Corrective actions are therefore first identified to overcome the urbanistic, technical and administrative criticalities identified. We then proceed with the evaluation of the costs associated with the corrective actions. These generally concern the costs of consultancy by sector experts and, in the case of more complex projects, the costs for insurance policies, assistance from scientific institutions, and services offered by a general contractor. Finally, each type of cost must be associated with a probability distribution, established based on opinions formulated by experts or following empirical market research conducted to define the ranges of cost variability. For each mitigation measure, the minimum, maximum, average and modal market costs are therefore defined, as well as the type of probability function (triangular, rectangular, Gaussian, etc.). The main objective of this phase is to ensure that the policies adopted are supported by sufficient financial resources to address the challenges and ensure the success of urban energy redevelopment interventions [39].

Phase 6. Preparation of estimate metric calculations and project economic frameworks for each type of intervention. This phase involves the compilation of documents detailing the expected costs for the implementation of the various urban energy requalification interventions. During this phase, the estimate metric calculations are processed, which represent a quantitative estimate of the materials, labour and other resources necessary to carry out each intervention and their costs. Estimate metric calculations provide a detailed overview of the physical components and related costs associated with each type of intervention. Furthermore, project economic frameworks are developed, which represent a complete financial evaluation of the planned interventions. Economic frameworks include expected costs for materials, labour, consultancy, any additional costs, taxes and other related expenses.

Phase 7. Preparation of the forecast financial statement and implementation of the CBA. This phase consists of the drafting of a document that provides a detailed assessment of the costs and financial benefits expected for each type of urban energy requalification intervention. The forecast financial statements are prepared, which

include the initial costs associated with the implementation of each intervention estimated in the previous phase of processing the estimate metric calculations and the project economic frameworks. Furthermore, the expected financial benefits deriving from the interventions are identified, such as energy savings, reduction of building operating costs, revenues deriving from tax incentives or government financing, and other related financial benefits. In addition, a cost–benefit analysis (CBA) is implemented to systematically and in detail evaluate the costs and benefits associated with each intervention. This analysis allows you to evaluate whether the planned investments are economically advantageous in the long term, comparing the expected benefits with the costs incurred. The CBA can lead to the estimation of a series of indicators and indices, such as the Internal Rate of Return (IRR), the capital recovery period (Payback Period), and the Net Present Value (NPV), useful for evaluating the economic and/or financial invalidity of the interventions [40]. A delicate phase concerns the estimate of the discount rate to be used to discount future cash flows at present. When the analysis is conducted from the point of view of the families benefiting from the interventions, the discount rate can be expressed in terms of the families' time preference rate. When the analysis is conducted from the point of view of a company, it is preferable to estimate the discount rate with the Weighted Average Cost of Capital (WACC) method. Finally, when the analysis is conducted from the point of view of a public body, it is preferable to express the discount rate in terms of the social rate of time preference of the entire community. Usually, the discount rates used in the energy sector vary in the following three ranges: high rates (5.5–7.5%) for owning families, intermediate (3.5–5.5%) for companies, and low (0–3.5%) when you want to incorporate the intergenerational effects of social and environmental sustainability [41].

Phase 8. Choice of indicator or performance index to be used in the risk analysis phase. In this phase, the objective is to select the right metric from a series of indicators and indices (Benefits, Revenues, Net Profit, NPV, IRR, Payback Period, Benefit–Cost Ratio, ROI, ROE etc.) to subsequently implement the analysis of the economic and/or financial risk of the planned interventions. The choice of the metric to be adopted is influenced by the type of analysis (whether economic or only financial), the scope of the intervention (residential, commercial, productive, of collective interest), the energy policy adopted (tax deduction, financing non-repayable fund, etc.) and the duration of the works. An often-used index is the IRR (Internal Rate of Return), as this metric is less influenced by the size of the project. The IRR is the value of the discount rate that makes the NPV zero [40]. When the duration of the intervention is rather limited (this is the case of an energy efficiency project for a single building), ROI is often preferred to IRR. ROI allows you to define the annual operating income of an investment compared to the total capital invested (both equity capital and debt capital) [42].

Phase 9. Implementation of risk analysis. In the implementation phase of probabilistic risk analysis via Monte Carlo simulation, computational techniques are used to evaluate the effects of uncertainty and variability in project results. This method involves the random generation of multiple possible scenarios, each with its inputs and parameters, to determine the probability of various outcomes and identify possible critical issues or opportunities associated with the project [43]. In particular, the costs associated with urbanistic, technical, and administrative criticalities are regarded as sensitive variables.

As these costs vary within their permissible range, according to the probability distributions defined during Phase 5, simulation enables us to obtain the cumulative probability distribution of the selected performance indicator or index.

Phase 10. Implementation of the risk assessment phase integrated with the ALARP logic. In this phase, by reading the graph representing the cumulative probability distribution we evaluate the probability that the chosen performance indicator/index is higher (or lower) than a certain threshold value. In this way, it is possible to evaluate the probability of financial and/or economic failure of urban energy redevelopment interventions. To introduce thresholds that are as objective as possible, in the protocol it was decided to integrate the traditional economic/financial risk assessment phase with the ALARP principle, in which threshold levels are established for risks considered "acceptable" and "tolerable" [44]. The tolerability threshold can be set concerning a probability of no less than 50% of having a performance indicator (or index) lower than or equal to its lowest useful value. For instance, if IRR is chosen as the metric, the risk is tolerable if there is a probability of no less than 50% of having an IRR lower than or equal to the discount rate used for the CBA. The acceptability threshold can be set concerning a probability of no less than 50% of having a performance indicator (or index) lower than or equal to the value of the same parameter obtainable in the absence of implementation of the project. For instance, if the IRR is chosen as the metric, the risk is acceptable if there is a probability of no less than 50% of having an IRR lower than or equal to the IRR obtained for scenario 0, i.e. when the efficiency interventions energy are not implemented [37, 38].

Phase 11. Definition of risk mitigation measures and assessment of residual risk. In the phase of defining the risk mitigation measures and evaluating the residual risk, actions aimed at reducing or managing the risk of economic/financial failure possibly recorded in the previous phase are identified and implemented. Subsequently, the residual risk is assessed, i.e. the level of risk remaining after the implementation of the mitigation measures, to evaluate the effectiveness of the strategies adopted. A new Monte Carlo simulation and a new risk assessment phase are therefore implemented, effectively making the protocol iterative.

4 Discussion and Conclusions

In the field of urban planning and energy management, efficiency and sustainability play a crucial role in the design and administration of modern cities [45]. In response to growing environmental awareness and the need to reduce greenhouse gas emissions, many countries are adopting policies and incentives to promote energy efficiency in buildings and urban infrastructure. However, the economic and financial evaluation of such interventions remains a complex challenge, requiring a strategic and systematic approach to balance long-term costs and benefits [46, 47]. The protocol conceived here represents an innovative attempt to address this challenge, offering a methodological guide for the economic evaluation of urban energy redevelopment projects supported by public incentive policies. The fundamental peculiarity of the proposed protocol lies in the adaptation of the ALARP principle to the financial context of urban redevelopment

projects. Unlike the conventional approach, which focuses on assessing health risks and potential loss of life, our study applies ALARP logic to analyse the risk of financial failure associated with urban redevelopment projects. This innovation requires a redefinition of tolerable and acceptable risk levels, adapting them to the specific economic and financial context of the aforementioned projects. The comparison with other research that uses the ALARP principle [33–38], highlights the originality of its application in our field of investigation. The different phases of the protocol illustrate the complexity and exhaustive nature of the decision-making process, which goes beyond traditional cost–benefit and risk analyses, including a careful survey of the critical issues (urban planning, technical, administrative) that characterize each policy to incentivize or finance urban energy interventions.

Although the protocol has only been defined on a conceptual level and has not yet been applied in practice, its potential is promising. However, during its development, some critical issues and limitations emerged that require attention. For instance, the phase of defining financial incentive policies could be complex and susceptible to regulatory and political changes over time, making it necessary to constantly update the protocol. Furthermore, practical implementation may encounter operational and bureaucratic resistance, requiring adaptation to specific local circumstances. Despite these challenges, the potential of the protocol to drive informed and sustainable decisions in the area of urban energy efficiency is evident.

In conclusion, we underline the importance of a holistic and integrated approach to the economic evaluation of projects, considering not only the direct financial costs and benefits but also the social, environmental and long-term impacts [48, 49]. Future research areas should focus on the refinement and empirical validation of the protocol, as well as on the analysis of its effects on urban planning and governance.

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