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SMART AND SUSTAINABLE PROJECTS AT THE ENERGY-DISTRICT LEVEL
HOW TO ASSESS THEM BASED ON THE CO-BENEFITS PARADIGM

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Acknowledgements

Three years have quickly passed since I first discussed with the Head of the Renewable Energy Institute and my group leader, at EURAC Research, the opportunity to undertake a Ph.D. path. The path has been neither straightforward nor smooth: I have employed all my energy and personal motivation to get there. Now I am finishing my Ph.D.; I accomplished in a timely manner and I am fully satisfied with the results. Thus, I feel much gratitude to Wolfram and Daniele for the opportunity they gave me.

Even though I was raised in Padova, it was actually a novel experience for me to get into touch with its prestigious University, where culture and knowledge are so immense, but where the procedures are at times complicated and some physical spaces quite uncomfortable. This is ironic, given that we concentrate on the topics of smartness and comfortable environments! I know that I was quite an atypical Ph.D. candidate, nevertheless I guess most of University colleagues and professors appreciated me, our interaction, and the novel type of relationships (*Keep calm and love aestimum*). Special thanks to my supervisor, professor Stellin, and to all my others friends, familiars, researchers, academics and people that spent their time discussing with me, exchanging emails, debating strategies, solving problems, and reviewing results.

I must apologize to my family: only by stealing time from Alessandra and from my lovely girls Matilde and Eleonora was it possible to achieve this result. Ladies, now it is our turn. Finally, this work is dedicated to those who were skeptical about this ending: please remember, a father of twins never gives up.

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Abstract

The main topic of this doctoral thesis is the co-benefit concept, here applied as an assessment paradigm to innovative urban projects. In this research, a co-benefit is defined as any positive impact or effect, regardless of the intentionality, exceeding the primary project goal. More specifically, because the projects here analyzed are those aiming at (re)developing smart and sustainable energy districts, CO_2 emission reduction and energy savings are considered the twin primary goals. To investigate the applicability of the assessment paradigm, the work focuses both on methodological and operative issues, each developed in a single research. The general topic and the four papers are summarized in chapter 1 "*Introduction and research papers presentation*", also including a brief overview of complementary research activities, and then further developed in as many chapters. The core of the work starts with two general investigations concerning (i) the co-benefits identification and classification under the smart-city perspective, and (ii) the application to them of the most suitable monetization techniques. Then, it concludes with two instances of investigative fieldwork into co-benefits, about (iii) the marginal implicit value of energy performance in residential properties, and (iv) the priorities declared by houseowners as they consider a deep-energy retrofit.

To identify and classify the co-benefits, with respect to the various project activities, it is necessary to establish a common lexicon among the various expressions and definitions employed by projects. This phase is also needed to define the boundaries of the investigation, as well as the reference scale, and to avoid double counting. In chapter 2 "*Overview and taxonomy of co-benefits based on European experiences*", I propose a classification rooted in practical experiences reported by projects dealing with the implementation of green neighborhoods and urban renewable-energy systems. Due to the vastness and diversity of urban projects labeled as smart, sustainable, or both, it was also necessary to identify a subset of them having similar characteristics, here named Smart and Sustainable Energy-District Projects (SSEDPs). Thus, the focus was on 36 finished or still-running SSEDPs funded by the European Union (EU) within two relevant initiatives: "Concerto" and "Smart Cities and Communities". The anticipated or already experienced co-benefits were extracted by accessing official sources (e.g., websites, reports) and reviewing them with respect to the specialized literature, obtaining 156

different expressions referring to positive impacts. After a thorough and iterative comparison by a group of experts, a short list of 19 key urban co-benefits is extracted. Finally, to show how relevant is the contribution of these projects to improving the quality of life of citizens and urban competitiveness, a smart-city-based taxonomy is elaborated, by sorting the co-benefits into seven groupings: smart natural environment, smart services, smart community, smart governance, smart economy, smart built environment, and smart mobility.

Chapter 3 "*Economic assessment methodologies*" faces the issue of providing an overview of suitable methodologies for economic assessment, and of creating a framework for evaluating the key urban co-benefits recognized by EU-funded SSEDPs. The aim is to explore the feasibility of a co-benefit approach to a cost-benefit analysis (CBA) being applied to the decision-making framework by quantifying, in monetary terms, all the positive effects (benefits or inflow), as well as the negatives (costs or outflow). Due to the specificity of some co-benefits, besides direct-market value, non-market techniques have been identified as applicable to price them. Such techniques investigate consumers' preferences starting from individual purchasing habits (revealed preferences) or asking them directly about their preferences (stated preferences). It showed that, for a minority of co-benefits, even the monetization of the human capital should be assessed to complete the whole picture. As a result, looking at the reference literature and involving a multidisciplinary team of experts, an "assessment menu" is developed, suggesting indicators and techniques. The menu also includes some estimated values reported by other studies, examples of practical application in similar contexts, and techniques or approaches suggested by analogy to the reference literature.

The chapter 4 "*A hedonic price model of energy performance of buildings*" is tested in the city of Bolzano. This estimation technique identifies price factors (transactions or asking prices) according to the premise that an asset's price is determined both by the intrinsic characteristics of the good being sold and extrinsic ones. The research constitutes the first attempt at breaking down the local residential property price and including, among the relevant factors, internal characteristics such as the energy performance certificate (EPC) class. By accessing a specialized real-estate website, 1,130 selling advertisements are collected, then geolocated, and analyzed by using Geographic Information System (GIS) software. The aim was to test the presence of spatial autocorrelation, and to eventually correct the estimation based on the ordinary least-squares (OLS) method. In fact, a neglected consideration of spatial relationships, in the presence of spatial dependence would lead to biased results. After a careful refinement of the sample, the

evaluation of the marginal contribution of EPC class in the determination of the asking price has been estimated in a 6.3% price premium, moving from lowest class (G) to middle classes (C or D), and a 9.5% when reaching the highest classes (A or B), *ceteris paribus*. Finally, the OLS-regression result is confirmed, after checking for spatial autocorrelation and testing the Spatial Lag model (the GIS software ArcMap and GeoDa were used).

In chapter 5 "*A multiple benefits approach to understanding citizen priorities for deep-energy retrofitting*", the focus shifts from a specific co-benefit to a specific target group. Here, priorities declared by houseowners approaching a deep-energy retrofit are shown and weighted, adopting a multi-criteria decision analysis (MCDA) method. According to the test-phase results, a decision tree with five criteria and 15 subcriteria has been designed: four in "thermal and hygrometric comfort"; three in "design and architectural quality", "acoustic comfort", and "economic benefits"; and two in "sustainability". Then, a pool of ten experts in the field of energy refurbishment and building works (selected among those working in South Tyrol) has been interviewed by applying the Analytic Hierarchy Process (AHP) technique, which enables evaluation of qualitative criteria through pairwise comparison. The "Super Decisions" software was used, which is specifically designed to support the data collection and results' validation of AHP. Not surprisingly, the "economic-benefits" side plays a relevant role (38% of the global importance). However, a cross-sector analysis of expected benefits dealing with better health and well-being of occupants reveals that they cover 41% of the overall motivation. These points should be carefully considered not only in the design phase of a private project but also in the communication strategies and within each participatory phase of any project where the decision-maker (private or public) differs from the occupant.

The thesis culminates with chapter 6 "*Conclusions*", where achieved results of all the four previously described investigations are briefly summarized and further developments are proposed as an impetus for deeper investigations or cross-cutting research.

Keywords

Co-benefits; smart and sustainable energy-district projects; smart city planning; revealed and stated preferences; spatial hedonic model; multi-criteria decision making; deep-energy retrofit; energy performance rating.

Sommario

Il tema principale di questa tesi di dottorato è costituito dal concetto di "co-beneficio" (in inglese *co-benefit*), qui inteso come un paradigma di valutazione di progetti urbani innovativi. In questa ricerca, il co-beneficio è definito come un qualsiasi impatto o effetto positivo che ecceda l'obiettivo primario del progetto, indipendentemente dalla intenzionalità o meno con cui esso si manifesta. Nello specifico, poiché i progetti qui analizzati sono volti alla creazione di distretti energetici intelligenti e sostenibili (in inglese *Smart and Sustainable Energy District Projects – SSEDP*s) o alla rigenerazione di quartieri esistenti, il loro obiettivo primario può essere considerato duplice: riduzione delle emissioni di CO_2 e raggiungimento di risparmi energetici. Per studiare l'applicabilità del paradigma di valutazione, il lavoro di tesi si concentra sia su questioni metodologiche che operative, ognuna sviluppata in una singola ricerca. Il tema generale e le quattro ricerche specifiche sono riassunti nel capitolo 1 *"Introduzione e presentazione dei research papers"*, che offre inoltre un breve *excursus* su attività di ricerca complementari. Poi, le quattro ricerche sono sviluppate in altrettanti capitoli della tesi. Il nucleo del lavoro si apre con due indagini generali relative a (i) identificazione co-benefici e loro classificazione in una logica di *smart city*, e (ii) definizione delle più opportune tecniche di monetizzazione a loro applicabili. Da qui il lavoro procede con due attività di investigazione e analisi sul campo dei co-benefici, ovvero (iii) determinazione del valore marginale implicito della prestazione energetica nel prezzo di offerta degli immobili residenziali, e (iv) pesatura dei benefici attesi dichiarati dai proprietari immobiliari nel commissionare una ristrutturazione energetica radicale (in inglese *deep energy retrofit*) della propria residenza.

Per identificare e classificare i co-benefici, in relazione alle differenti attività di progetto, è stato necessario stabilire un lessico comune tra le varie espressioni e definizioni rintracciabili in diversi contesti. Si è reso inoltre necessario, nella fase preliminare, definire i confini della ricerca, così come la dimensione di riferimento, per evitare un doppio conteggio dello stesso co-beneficio. Nel capitolo 2 *"Descrizione e tassonomia dei co-benefici sulla base delle esperienze europee"*, si propone una classificazione fondata sulle evidenze riportate dai progetti riguardanti la realizzazione di quartieri sostenibili e di sistemi energetici urbani con integrazione di fonti energetiche rinnovabili. Data la vastità e diver-

sità dei progetti urbani definiti smart, sostenibili, o da entrambe i termini, è stato necessario individuare un sottoinsieme di progetti con caratteristiche simili ed equiparabili. Ad essi è stata attribuita la dicitura di *Smart and Sustainable Energy District Projects – SSEDP*s. In tal modo, l'attenzione della ricerca si è concentrata su 36 SSEDPs, alcuni già conclusi, altri ancora in esecuzione, finanziati dall'Unione Europea (UE) all'interno di due importanti iniziative: "Concerto" e "Smart Cities and Communities". I co-benefici, attesi o già riscontrati, sono stati ottenuti accedendo alle fonti ufficiali (quali siti web e report) e incrociandoli rispetto alla letteratura specializzata di settore. Si sono così ottenute 156 diverse espressioni riferibili agli impatti positivi. Dopo un confronto approfondito e iterativo condotto da un gruppo di esperti, si è giunti alla formulazione di una lista sintetica di 19 co-benefici urbani di preminente interesse. Infine, per mostrare quanto rilevante sia il contributo di questi progetti al miglioramento della qualità della vita dei cittadini e della competitività urbana, è stata elaborata una tassonomia dei co-benefici basata sulle sette dimensioni della smart city (ambiente naturale, servizi, comunità, governance, economia, ambiente costruito, mobilità).

Il capitolo 3 "*Metodologie di valutazione economica*" affronta il problema di fornire una panoramica di quali possano essere le metodologie adeguate per la valutazione economica dei co-benefici, e di creare un quadro di riferimento applicabile ai principali co-benefici urbani evidenziati dagli SSEDPs finanziati dalla UE. L'obiettivo è quello di esplorare la fattibilità di un approccio allargato, incorporante i co-benefici, nella formulazione di analisi costi-benefici (in inglese *Cost-Benefit Analysis - CBA*), e pertanto di offrire al quadro decisionale una quantificazione monetaria di tutti gli effetti positivi e negativi. A causa della specificità di alcuni co-benefici, oltre alla identificazione diretta del valore di mercato, sono state ipotizzate le tecniche non di mercato strategicamente applicabili per la definizione del loro valore. Tali tecniche permettono di indagare le preferenze dei consumatori a partire da singole abitudini di acquisto (preferenze rivelate) o chiedendo loro direttamente di esprimersi sulle preferenze (preferenze dichiarate). Per una minoranza di co-benefici, anche una monetizzazione del valore del capitale umano dovrebbe essere inclusa per completare l'intero quadro. Come risultato, ancora una volta riferendosi alla letteratura scientifica specializzata e coinvolgendo un team multidisciplinare di esperti nel dibattito, è stato possibile sviluppare un "menù di valutazione", suggerendo indicatori e tecniche applicabili ai progetti esaminati. Il menù comprende anche alcuni valori stimati riportati da altri studi, esempi di applicazione pratica in contesti simili, e le tecniche o approcci suggeriti per analogia alla letteratura di riferimento.

Nel capitolo 4 "*Un modello di prezzo edonico per l'analisi della prestazione energetica negli edifici*" è testato nella città di Bolzano. Questa tecnica di stima individua i fattori determinanti il prezzo dell'immobile (applicabile alle transazioni quanto ai prezzi di offerta, come in questo caso) in base alla premessa che esso sia determinato da caratteristiche intrinseche del bene stesso posto in vendita e da caratteristiche estrinseche. La ricerca costituisce un primo tentativo di scomporre il prezzo di offerta degli immobili residenziali di Bolzano comprendendo tra i fattori rilevanti intrinseci anche la classe riportata dall'attestato di certificazione energetica (in inglese *Energy performance certificate - EPC).* Accedendo a un portale internet immobiliare specializzato, sono stati raccolti 1.130 annunci, successivamente geolocalizzati e analizzati utilizzando sistemi informativi geografici (in inglese *Geographic Information System - GIS*). Lo scopo di questo passaggio, aggiuntivo rispetto ad un classico modello edonico, è stato quello di verificare la presenza di auto-correlazione spaziale, ed eventualmente correggere la stima ottenuta sulla base del metodo dei minimi quadrati (in inglese *Ordinary Least Squares - OLS*). Questo poiché, come evidenziato dalla letteratura, una non considerazione delle relazioni spaziali, in presenza di forte dipendenza spaziale, porterebbe a risultati distorti della stima. Dopo un attento affinamento del campione, il contributo marginale della classe energetica nella determinazione del prezzo di offerta, prendendo come base di riferimento gli immobili in classe peggiore (G), è stato stimato in un aumento del 6,3% per le classi medie (C o D), e del 9,5% per le classi più elevate (A o B), *ceteris paribus*. Infine, il risultato del modello di regressione dei minimi quadrati è stato confermato, dopo averlo verificato nella componente di autocorrelazione spaziale testando il modello spatial-Lag (per queste fasi sono stati utilizzati i software GIS ArcMap e GeoDa).

Nel capitolo 5 "*Un approccio basato sui benefici multipli per la comprensione delle priorità dei cittadini nelle ristrutturazioni energetiche*", l'attenzione è stata spostata dall'analisi di un co-beneficio specifico a quella di un target specifico. Qui, le priorità dichiarate dai proprietari di immobili residenziali che si approcciano ad un *deep energy retrofit* della propria abitazione sono espresse e ponderate adottando un metodo di analisi di decisone multicriteri (in inglese *Multi-Criteria Decision Analysis - MCDA*). Sulla base dei risultati di una prima fase test, è stato disegnato un albero del processo decisionale articolato in cinque criteri e 15 sotto-criteri, così suddivisi: quattro in "comfort termico e igrometrico"; tre in "design e qualità architettonica", "comfort acustico", "benefici economici"; due in "sostenibilità". Successivamente, un gruppo di dieci esperti nel campo della ristrutturazione energetica e nel settore dell'edilizia residenziale (selezionati tra quelli attivi in Alto Adige),

è stato intervistato applicando la tecnica dell'*Analytic Hierarchy Process* (AHP), che consente la valutazione di criteri qualitativi attraverso il confronto a coppie. In questo studio è stato utilizzato il software "Superdecision", che è specificamente progettato per supportare la raccolta dei dati e la validazione dei risultati AHP. Dai risultati ottenuti emerge, come era intuibile dato il contesto normativo attuale, che la dimensione dei "benefici economici" gioca un ruolo considerevole nella scelta (38% della rilevanza globale). Tuttavia, un'analisi trasversale dei benefici attesi che coinvolgono aspetti della salute e del benessere degli occupanti rivela che questi coprono il 41% della motivazione complessiva. Lo studio evidenzia quindi come tali punti debbano essere attentamente considerati non solo in fase di redazione dei singoli progetti, ma anche nelle strategie di comunicazione e all'interno di ciascuna fase di partecipazione nel caso di progetti nei quali il decisore (pubblico o privato) non corrisponda all'occupante.

La tesi termina con il capitolo 6 "*Conclusioni*", dove sonno riepilogati i percorsi delle quattro indagini precedentemente descritte e sono brevemente riassunti i risultati. Sono inoltre evidenziati possibili sviluppi futuri, proposti come un impulso per indagini più approfondite o per ricerche trasversali.

Parole chiave

Co-benefici; progetti per quartieri energeticamente intelligenti e sostenibili; pianificazione intelligente della città; preferenze rivelate e dichiarate; modello edonico spaziale; analisi multi-criteri; ristrutturazione energetica; valutazione della prestazione energetica.

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Chapter 1 - Introduction and research papers presentation

The research activities reported in this work have been conducted within the Doctoral School of Management Engineering and Real Estate Appraisal at the University of Padua. They aim to contribute to a better understanding of the positive effects generated by Smart and Sustainable Energy-District Projects, by adopting the co-benefits assessment paradigm.

The need for a prompt transition toward more climate-friendly, efficient, and sustainable urban settlements and energy systems is today widely recognized (Droege 2008; ICLEI, UN-HABITAT, UNEP, 2009; Pfenninger et al. 2014). Different strategies can be chosen, which may differ widely in time, scale, direction, and priorities (Lewis et al. 2013; Sovacool 2016). Although they are at the top of many policy agendas (e.g., European Commission 2014b), these strategies often face strong resistance to being translated into action (van Doren et al. 2016). One of the key barriers to implementation is the wide time discrepancy between the delay in appreciable environmental benefits and the immediate cost of actions (Mayrhofer and Gupta 2016). Trying to solve this impasse, the climate-energy policies encompass the concept of "co-benefits" in their rhetoric, to shift the perspective from mitigation costs to development opportunities (Davis et al. 2000) and to highlight other socio-economic advantages. Indeed, such policies, if effectively designed, correctly run and properly assessed, should result in multiple benefits outweighing implementation costs (IPCC 2007). Considering this perspective, the European Union (EU) also has established its medium-term energy-climate goals and defined a long-term roadmap for the transition towards a less energy-intensive and environmental-degrading economy, named "low carbon". Within this vision, cities are recognized as key players, due to their two-fold characteristic of relevant energy sinks, as well as wealth sources, and therefore innovative projects are promoted. Smart and Sustainable Energy-District projects (SSEDPs), although mainly focused on reduction of carbon dioxide (CO_2) emissions, by implementing energy efficiency measures and exploiting renewable sources, are considered to be carriers of additional positive impacts (Lewis et al. 2013). Nevertheless, there is a piecemeal consideration of urban co-benefits within projects' assessment

phases (Di Nucci and Spitzbart 2010). This is due to the lack of a framework, more than methodologies, to assess them (IEA 2014a; US EPA 2011). Only by counting good SSEDPs co-benefits (Ürge-Vorsatz et al. 2009) their appreciation will be improved, enhancing decision makers' commitment toward ambitious projects launching and successful implementation.

Co-benefits are those positive effects arising from a project, both intentional and not, exceeding the intended primary goal. These effects cover a wide spectrum of different typologies, ranging from tangible (e.g., increased market value in energy efficient buildings) to intangible effects (e.g., firms' enhanced innovation in technology adoption). Some recent experiences, as well as ongoing smart energy city projects, besides the primary twofold goal of reducing emissions and energy needs, declare that additional positive effects - the so-called "co-benefits" - can be reasonably expected. In this context, the here presented research stresses how co-benefits identification and evaluation may help in operationalizing positive effects of SSEDPs. The aim is to contribute in filling the gap in the existing literature, which mainly focuses on benefits strictly related to measures implementation. The novelty of the research lies in transferring the co-benefit concept into a project-oriented approach, including the management phase and stakeholders interaction, and it is based on an in-depth review of co-benefits literature and on the analysis of European funded projects.

Basically, the research path is developed following four research questions:

– Which kind of co-benefits, if any, are expected from SSEDPs development and implementation?

– Which economic evaluation methodologies are already available to estimate the co-benefits?

– Does energy efficiency have a price premium on the residential property market, as the co-benefits literature suggests?

– Which co-benefits are expected by citizens undertaking deep energy retrofit works, on their own residential building?

Consequently, the thesis is composed of four papers, presented at international scientific conferences during the last three years. Most activities have been undertaken also in the context of a "smart cities and communities" project. Indeed, in mid-2014, the Municipality of Bolzano joined a five-year project, devised by EURAC Research and funded by the

European Union under the FP7 program. This so-called "SINFONIA" project, whose acronym stands for "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions", is going to develop various smart measures within the city. The main benefit for single users will be a deep-energy retrofit of selected dwellings in publicly-owned residential buildings, while a relevant result for the community will be the implementation of an innovative urban-information infrastructure. Such an infrastructure will interact with users through some smart points, called "totems", to be located in the most strategic areas of the city. This project also concerns the implementation of innovative energy generation and distribution technologies within existing urban districts and involves multiple stakeholders (research institutions, energy companies, social-housing agencies, and municipalities) from several European countries.

1.1 First research paper

The first paper tackles the following research question: which kinds of co-benefits, if any, are expected from SSEDPs development and implementation? To answer this, an extensive literature review of co-benefits deriving from energy-efficiency projects and CO_2 mitigation policies has been done. In parallel, a selection of 36 European SSEDPs was examined, to understand what co-benefits they mention, both achieved or foreseen. As a first result, co-benefits related to project-management activities are added to those traditionally derived from the execution phase, providing a comprehensive overview (a list of 19 key co-benefits). Then, co-benefits are explained and discussed, linking expectation of projects' positive effects to literature findings. Finally, a new taxonomy, based on smart–city characteristics, has been suggested. This provides an innovative framework that enables researchers, developers, and decision makers to better understand citizens' priorities, attitudes, and expectations concerning the co-benefit concept. The purpose of this research has been, therefore, to better understand and assess the multiple positive aspects related to the implementation of smart-energy projects at the district scale. This working paper was presented at the Royal Geographical Society Annual Conference 2015 (September 1–4, 2015, Exeter, UK) (see: Bisello et al. 2015b).

1.2 Second research paper

The second research paper further elaborates the issue of co-benefits estimation. Thus, the following steps are undertaken. First, an overview of the methodologies for the economic assessment of co-benefits related to SSEDPs is given. Second, starting from the previously defined framework, the various techniques are analyzed, identifying the most appropriate with respect to targeted stakeholders and expected outcomes. As a

result, a clear and comprehensive pool of assessment methodologies, a so-called menu, has been provided. This menu, tailored to a specific project type, and operationally applicable, would sustain the funding, public acceptance and political commitment for SSEDPs, enabling the various stakeholders to better understand the entire value of the economic project, besides energy savings and CO_2 reduction. This paper has been presented at the Smart and Sustainable Planning for Cities and Regions International Conference 2015 (November 19–20, 2015, Bolzano, Italy) jointly organized by EURAC Research and the International Society of City and Regional Planners (ISOCARP). The paper is already published in the conference proceedings (see: Bisello et al. 2017a).

1.3 Third research paper

The third paper shifts the focus from the general picture to the specific issues. Here the aim is to verify, in a specific territorial context, whether and how the energy efficiency has a price premium in the residential real-estate market. Thus, a spatial hedonic price model has first been theoretically designed and then was started to be tested in Bolzano (Italy). According to scientific literature, a pool of potentially useful variables have been identified to build up the multivariate methodology. Through a web-based survey involving local real-estate agencies, a database of 1,130 sales advertisements in the city of Bolzano has been built up. Data has been spatialized with a geographical information system (GIS), to better understand how extrinsic characteristics, besides intrinsic ones, affect the local market and to test them for spatial autocorrelation. Preliminary results showed that the energy performance classification (EPC) is recognized as a relevant issue in the definition of the registered offer prices only in the "premium" classes (A and B), while intermediate are less considered. The strongest and full appreciation needs therefore further development of citizen's awareness, and also a knowledge increase by real estate agents. As a next step, by combining results with additional information available at the district level, such as buildings construction age and current energy consumption, it will be possible to assess/evaluate the socio-economic value of additional large-scale initiatives, improving energy performance on the existing building stock.

The suggested methodology and consequent operative steps were presented as a conference paper at New Metropolitan Perspective - International Symposium Towards Horizon 2020 (May 18–20, 2016, Reggio Calabria, Italy) organized by the Mediterranean University of Reggio Calabria. The paper is already published in the conference proceedings (Bisello et al. 2016d).

First results of spatial analysis and regression models were presented and discussed at the XX ASITA Annual Congress 2016 (November 8–10, 2016, Cagliari, Italy) organized by the Federation of Scientific Associations of Spatial and Environmental. An extended abstract is already published in the conference proceedings (see: Bisello et al. 2016a).

1.4 Fourth research paper

Finally, the fourth research paper addresses the co-benefits' topic from the perspective of a specific stakeholder category: the householder. To reveal citizen expectations when undertaking a deep-energy retrofit, a pool of ten highly skilled professionals in this field was interviewed. They were selected among those certified as CasaClima experts and working in the local south-Tyrolean housing market. Experts were asked to disclose, on the basis of their practical experience, what are the motivations driving the householder's choice. An Analytic Hierarchy Process (AHP), which is one of the most widely applied techniques of multi-criteria decision analysis (MCDA), was implemented to compare and weigh the various motivations. It was found that the primary single driver is currently the benefit of gaining a "tax deduction". On the other hand, the expectation of health and well-being benefits (due to increased thermo-hygrometric comfort, indoor spatial quality, and acoustic comfort) play as well a significant role in the decision. The lesser value is attached to sustainability benefits (e.g., reducing environmental pollution), confirming how raising awareness and education in this field should be encouraged.

The methodology and results of the first eight interviews were presented at the 52nd ISOCARP Annual Congress (September 12–18, 2016, Durban, South Africa) organized by the International Society of City and Regional Planners. This paper is already published in the conference proceedings (see: Bisello et al. 2016b).

1.5 Other research activities

Over the three-year period 2014–2016, other research activities were undertaken. Although not presented as extended results in this thesis, they contributed to stimulating the debate, providing momentum for additional investigations, and suggesting further research paths. In particular, I had the opportunity to be involved as co-author in three international journal papers, respectively, addressing (i) the topics of barriers to the implementation of smart-city projects, (ii) the development of a definition of the smart-energy city, and (iii) conceptualizing the paradigm of "multi-layered density" to overcome the critics of the "renewable energy sprawl". These journal papers are briefly described below:

(i)   Implementation of smart and sustainable energy projects in urban areas encounters various barriers. These barriers range from common financial shortages to specific constraints, which depend on the local socio-economic, environmental, and political characteristics of each city. The main aim of the paper is to apply a case-based learning methodology to predict barriers to a given smart-and-sustainable energy project. This methodology is applicable and replicable for urban planners and decision-makers at various territorial levels to facilitate and accelerate the implementation of similar projects (see: Mosannenzadeh et al. 2017).

(ii)   Smart-energy city is an emerging concept in urban development, aiming to optimize urban energy systems and improve the quality of life of citizens. However, smart-energy city development requires a well-defined and consistent conceptual core in order to ensure its accurate interpretation and successful implementation. This research aims to define smart-energy city development not only in a theoretical context but also in terms of practical solutions. Results suggest that sustainable application of information and communication technology, a collaboration of multiple stakeholders, and integration of multiple urban-energy domains, mainstreamed into energy specific targets, enable distinguishing real from merely labeled smart-energy city development (see: Mosannenzadeh et al. 2016).

(iii)   The transition from fossil fuels to renewable resources is highly desirable to reduce air pollution and improve energy efficiency and security. Many observers are concerned, however, that the diffusion of systems based on renewable resources may give rise to energy sprawl, i.e. an increasing occupation of available land. The paper addresses these critics and concludes that the diffusion of innovation in this field will lead not to an energy sprawl but to a new energy system characterized by multi-layered density: a combination of technology, organization, and physical development (see: Moroni et al. 2016).

I had also the pleasure to be leading author in two book Chapters, in as many national publications, dealing with (i) the smart-city concept, from an energy perspective, and (ii) the development of climate-energy strategies at territorial level:

(i)   The first is an analysis on the role of an approach to smart-city development in tackling the energy issues at urban level, within regeneration processes (see: Bisello and Vettorato 2014);

(ii)   The second offers a comparison between two territorial energy plans developed by South Tyrol Autonomous Province. It stresses the analogies and differences

reflecting the changes in the administrative context, social sensibility, and environmental perspective leading to the development of these two climate-energy strategies (see: Bisello et al. 2015a).

Other research results, developed within the EU project SINFONIA, were presented in international conferences, although not included in the thesis. These activities concern (i) effective methods to assess the project participants' awareness about the co-benefits concept and to raise their consciousness, (ii) the way to assess the interest and willingness to pay expressed by citizens toward an innovative urban-information infrastructure:

(i) A participatory technique, flanked by a structured questionnaire, is suggested as a tool to introduce the co-benefit concept to SINFONIA project partners. Being more sensitive to the positive effects of the projects and having a reference framework, they will probably better understand how smart-district activities can help the cities to become more competitive. Unpublished work presented at SIEV Symposium 2016 (April 14–15, 2016, Rome, Italy) organized by Italian Real Estate Appraisal and Investment Decision Society (see: Bisello et al. 2016c).

(ii) The diffusion and integration of the information and communication technologies (ICT) in the urban environment is a pillar of the current smart-city development approach. In designing and construction of an innovative urban information infrastructure, enabling the users' interaction and communication, it plays a prominent role to understand how and if the project meets users' expectations. Thus, a Choice Experiment (CE) is here applied, showing, after a first test phase, that citizens are really interested in innovative services, providing info and Wi-Fi connection, and also in having charging points for electric vehicles. Presentation held at the XXXVII Italian Conference of Regional Science (September 20–22, 2016, Ancona, Italy). This paper is already published in the conference proceedings (see: Bisello and Grilli 2016).

Finally, I had the opportunity to actively contribute in the organization of science events, such as the international conference on "Smart and Sustainable Planning for Cities and Regions" (see: Bisello et al. 2017b) and in the dissemination and educational activities known as the "Long Research Night" or the Erasmus Mundus Project SUSTAIN, that were great moments for debating and sharing my research activities and findings.

Chapter 2 - Overview and taxonomy of co-benefits based on European experiences

The current debate on co-benefits highlights how this concept may help in operationalizing positive effects of low-carbon policies and measures. Under this "umbrella", all the relevant benefits distributed throughout the sustainable development dimensions should be listed and assessed. However, previous studies focus mainly on those benefits strictly related to measuring implementation. The novelty of this study lies in transferring the co-benefits concept into a project-oriented approach: to achieve this aim, a selection of European-funded projects, dealing with the development of smart and sustainable energy districts, is analyzed. As a first result, co-benefits related to project-management activities are included, providing a comprehensive overview. Then all the recognized co-benefits are explained and discussed, linking project statements to literature findings. Finally, to overcome the traditional partition of co-benefits among the four dimensions of sustainability (i.e. social, economic, environmental, and political) a new taxonomy, based on smart-city characteristics, is suggested. This provides an innovative framework, enabling researchers, developers, and decision makers to better understand citizens' priorities and attitudes toward the co-benefit concept. The main purpose of this Chapter is, therefore, to introduce the reader to the topic, contributing to a better understanding of the multiple positive aspects related to the implementation of smart-energy projects at the district scale.

The Chapter is organized as follows: the next Section offers a brief overview on current EU climate and energy policies and recounts the co-benefits, as well as the smart- city concepts, and explores various initiatives embracing energy-district projects, to contextualize them in the spatial, temporal, and cultural dimensions. The second Section explains the various steps undertaken to investigate and classify the co-benefits. The third Section examines and discusses the key urban co-benefits, with respect to causes and effects, and introduces our innovative taxonomy.

2.1 European milieu and background concepts

2.1.1 <u>EU climate-energy policies</u>

In 2007, the European Union (EU) leaders 'unanimously declared' a shared commitment to reduce greenhouse-gas (GHG) emissions. At the end of 2008, the EU Council and the Parliament translated this commitment into EU legislation by adopting the "climate and energy package". While aiming at a 20% reduction in GHG emissions (from 1990 levels), an increase to 20% of EU energy from renewable sources, and a 20% improvement in energy efficiency, this pact is also known as the "20-20-20 package". These three targets are also incorporated into the Europe 2020 strategy concerning "smart, sustainable and inclusive growth", which addresses several issues such as employment, research and development (R&D), education, poverty, and social inclusion. Later, in 2011, starting from the "20-20-20 package", the EU elaborated the Roadmap 2050 to achieve in the long term a more climate-friendly and low–carbon economy. The Roadmap 2050 recommends all each members cut their own emissions to a level at least 80% below the 1990 levels, involving all sectors and developing cost-efficient pathways, i.e. making the transition feasible and affordable. The comprehensive overview on EU climate and energy policies offered by da Graça Carvalho (2012) is currently integrated into the Framework 2030, adopted in 2014 (European Commission 2014b). It revises upwards the previous 2020 binding targets yet higher for 2030, and, according to the Roadmap 2050, confirms the milestone of -40% in GHG emission, flanked by at least a 27% share for renewable energy and an equally large increase in energy efficiency.

In parallel, the EU is also recognizing how the climate, environmental, and economic challenges have a strong urban dimension (European Commission 2014a). One side of the coin identifies cities as key elements of social and economic innovation, as milieus where consumers, workers, and businesses are concentrated, delivering 67% of EU GDP (Ricci and Macchi 2015). The other side points out how poverty, segregation, energy consumption, and pollutant emissions often manifest themselves there (European Commission 2014a). This convergence clearly explains why cities are recognized as pivotal players for the development of a smart, sustainable, and low-carbon economy (European Commission 2014b). Consequently, sustainable-energy strategies and projects, like those developed in the framework of the Covenant of Majors initiative, launched in 2008, are encouraged and funded.

2.1.2   The smart city concept

The "smart city" concept has become extremely relevant in recent years, attracting the interest of several players, such as academics, governmental bodies, and industries, and spreading over different research fields (Lombardi et al. 2012; Manville et al. 2014; Neirotti et al. 2014). So it is no wonder that a unique definition of a smart city is still missing, although the concept is widely investigated (Mosannenzadeh and Vettorato 2014). A related open question also remains what are the number and labels of the various elements (Hollands 2008) or otherwise named components (Lombardi et al. 2012; Mosannenzadeh and Vettorato 2014), dimensions (Santis and Fasano 2014), characteristics (Caragliu et al. 2009; Giffinger et al. 2007; Giovannella 2013; Manville et al. 2014), or domains (Neirotti et al. 2014) of the ideal smart city. Similarly, there is no agreement on the meaning of the extent of so-called smart city projects, embracing a broad spectrum of experiences in various fields, which render it often hard to compare with common metrics. Within this heterogeneous world, so far only partially explored, it appears that energy-focused projects are numerous and relevant (Neirotti et al. 2014), due to the two-fold characteristics of urban areas (as mentioned before).

2.1.3   The co-benefit concept

Similar to the smart city, the term "co-benefit" is also spreading widely across scientific publications. Although it emerged in the 1990s (Davis et al. 2000) in the context of greenhouse-gas mitigation policies, this concept has only recently been specifically investigated, leading to its becoming a major topic in the climate-energy debate (Ürge-Vorsatz et al. 2014). As clearly shown in the latest thematic literature review by Mayrhofer and Gupta (2016), there is an average increase of 15% in the number of articles per year. Nevertheless, the debate on terminology and the underlying concepts is still open. Because scientific literature proposes several nomenclatures and definitions, some of which can coincide, while others have different meanings, an effective visual map like the one suggested by Ürge-Vorsatz et al., (2014) is helpful to contextualize the co-benefits. According to Mayrhofer and Gupta (2016) and Ürge-Vorsatz et al. (2014), "co-benefit" is mostly used to refer to any positive impact or effect, regardless if intentional or not, that exceeds the primary policy goal. Quite similar is "side-benefit", although communicating an implicit ranking: a secondary effect that is somehow taken into account (Lovins 2004), whether implicit or intentional (Davis et al. 2000). In contrast, "ancillary benefit" mainly refers to an impact that occurs as an incidental consequence of a targeted policy (see also Davis et al. 2000). However, the literature does not always consistently follow the above-mentioned distinctions. It is also worth mentioning the term "multiple benefits",

supported by several notable organizations and institutions, such as the Intergovernmental Panel on Climate Change or International Energy Agency or US Environmental Protection Agency (IEA 2014a; IPCC 2011; US EPA 2011). They adopt this locution to indicate the broad range of positive outcomes, energy as well as non-energy related, without prioritizing them. Although "multiple benefits" seems to be the most appropriate definition to express a holistic balance among the various aims addressed by a policy or project, we focus on co-benefits because the policy or project main objective(s) are usually lesser known and not assessed in detail (Williams et al. 2012).

2.1.4   The European way to smart and sustainable energy districts

Approaching the heterogeneous world of smart city projects and related co-benefits requires a clear definition of both the content and boundary conditions of such projects. The first is here resolved by selecting projects tackling urban-energy issues, the latter by analyzing specific European Union funding programs.

Since 1984, multi-year funding programs have been developed by the European Union to support and foster research and technological development in the European Research Area. In the last decade, the European Union encouraged cross-sectorial urban-energy renewal through specific funding calls, within the sixth and seventh European Research Framework Programme, also known as FP6 and FP7. Such projects, implementing measures on new as well on existing urban districts, overcome the previous single-building approach. Benefits occurring in demonstration sites, in terms of improved energy performances, energy saved, or produced by renewables, and the tons of CO_2 avoided, are widely known (Pol and Lippert 2010). Moreover, they are used as the main examples to communicate the value of the project to the involved stakeholders, as well as to the general public. Aiming to demonstrate the feasibility of innovative solutions as well as cutting-edge approaches, such projects should involve research centers, universities, and partners from business and industry. Looking at funding requirements, mandatory for projects eligibility in this field, is the establishment of a temporary consortium of partners from various member and associate countries. Finally, having to be implemented into real world urban settlements, the inclusion of local authorities is generally required. In some cases, the previous involvement of the city government into the Covenant of Majors is also a preliminary condition.

To date, the Concerto initiative is one of the most relevant EU accomplished experiences in the field of sustainable energy districts. It covers 22 member states plus Switzerland, and 58 cities and communities. Overall, 22 projects, ranging from three to five years in

duration, were funded: the first nine projects under a FP6 call in year 2003, nine projects under the last FP6 call in year 2005, and last four projects under the first FP7 call in year 2008. The main objective of the Concerto initiative was to reduce CO_2 emissions in neighborhoods (Immendoerfer et al. 2014), in some cases up to making them carbon neutral (e.g., the Eco-life project at Høje Taastrup in Denmark, Kortrijk in Belgium, and Birstonas in Lithuania). More specifically, these projects aimed "*to demonstrate that the energy-optimisation of districts and communities as a whole is more cost-effective than optimising each building individually, if all relevant stakeholders work together and integrate different energy-technologies in a smart way*" as reported by the EU Smart Cities Information System (SCIS) (see: smartcities-infosystem.eu).

The Concerto initiative has paved the way to the subsequent, and still ongoing, Smart Cities and Communities European Innovation Partnership (SC&C) initiative, which addresses the challenge of making entire cities energy-smart. Again, the energy issues are considered at the district level, overcoming single-building intervention, but the novelty of the SC&C approach lies in a more extensive integration of innovative energy-efficient solutions with information and communication technologies (ICT), which in fact shift the focus from the sustainable development approach to the smart-city concept. Additionally, more emphasis is placed on scalability and the replication potential of interventions. Nevertheless, *"the ultimate outputs, such as the amount of load shifting and reduced CO_2 emissions"* still remain the focus of smart-projects' monitoring and evaluation (European Commission 2014c). For the purpose of our research, we limited the investigation of the SC&C initiative to 14 still ongoing projects (May 2015), funded under two different FP7 calls (ten projects in year 2012 and four projects in year 2013). It is worth mentioning that, although the FP7 has expired, the SC&C initiative is still going on under the Horizon 2020 (H2020). The first H2020 projects were funded in the early months of 2015. Because such projects are in a very early stage, quite unripe and mostly without official deliverables, they were not considered in this paper. Nevertheless, their evolution can be easily monitored through the newly implemented SCIS, which is also tackling the valuable heritage of the Concerto database.

On the basis of our screening of EU demonstration projects, one might say that a Smart and Sustainable Energy-District Project (SSEDP) combines both above-mentioned concepts, introducing cross-cutting approaches in the sustainable energy field. They take advantage of previous experiences, emphasizing the role of a strong interconnection between hard and soft measures, sustained by the application of the ICT. A general definition can be formulated, keeping in mind the overall rules previously cited and the most relevant specific criteria detailed in the calls for funding of the two above-mentioned

initiatives. According to that, a SSEDP is here defined as a European international co-funded cooperation project, applying outstanding energy technologies within urban settlements, involving multiple stakeholders, and including the local government in the consortium. Its primary two-fold goal is shrinking CO_2 emissions and reducing the need for fossil-energy sources by improving efficiency or shifting fuels. Under this definition we grouped 36 SSEDPs, involving 123 communities within Europe: the Concerto initiative implemented in 58 demonstration cases (26 cases under the first generation, 19 cases under the second, and 13 cases in the third) and the first stage of the SC&C initiative, foreseen to be applied in 65 cases (56 under the 2012 call and 9 under the 2013 call). Basically, a SSEDPs database is established, as graphically translated into Figure 1.

SMART CITY PROJECTS				
36 SMART AND SUSTAINABLE ENERGY DISTRICT PROJECTS				
22 CONCERTO PROJECTS			14 SMART CITIES AND COMMUNITIES PROJECTS	
EU FP6 2003	EU FP6 2005	EU FP7 2008	EU FP7 2012	EU FP7 2013
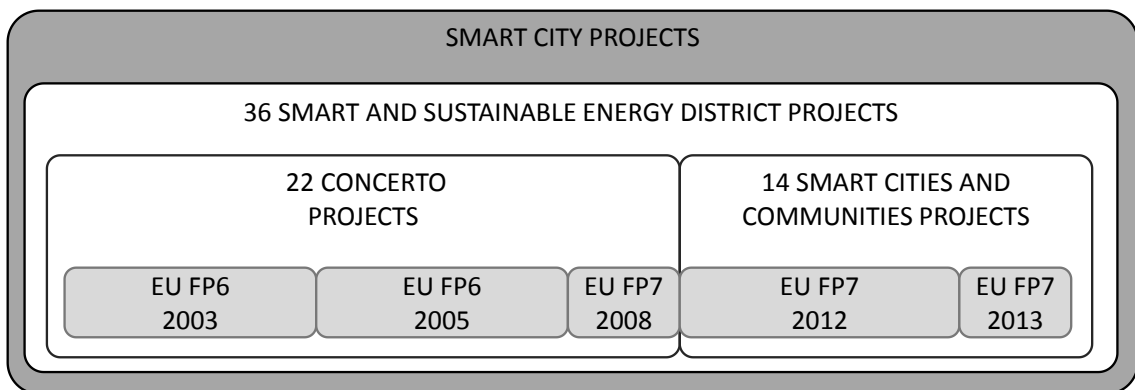
Figure 1: The SSEDPs database

2.2 SSEDPs' co-benefits investigation

This Section explains the general methodology applied to co-benefits investigation and details the four steps tackled to proceed from raw information collection to a smart-city framework-based taxonomy.

The research method used is rooted in empirical case analysis and literature research. An on-line investigation has been undertaken, based on open-access sources representing the official point of view of project consortia. Due to the recurrent consortia composition, these sources synthesize the findings and expectations of a large population of stakeholders, ranging from researchers to local officers and technicians, and from practitioners to decision makers. Then the raw data has been classified and refined by experts during workshops, merging closely-related statements and rewording them for the sake of improved readability. Our approach is similar to that followed by (Martin et al. 2014) to define a comprehensive list of relevant research questions related to low-carbon energy in cities. The main difference lies in addressing a wide range of issues through their official reports instead of through a specific on-line survey.

2.2.1   Step 1 - Open access sources

Official websites of each single SSEDP have been accessed between January and June 2015. Deliverables and webpages have been investigated to gather information on SSEDPs co-benefits, if any, regardless of being achieved or solely expected. Additionally, to improve the quality and homogeneity of information, joint initiatives such as Concerto Premium, European Innovation Partnership on Smart Cities and Communities, My Smart City District, and the European Community Research and Development Information Service (CORDIS) have been accessed, in the same way and during the period as above. To identify potential co-benefits anticipated by projects, we adopted a few basic criteria, according to those cited in Section 2.3: a co-benefit (i) exceeds the main project's objective(s), (ii) has a positive meaning, and (iii) is generated by, or strictly related to, project activities. Only statements meeting all three criteria were considered for further investigation. Concerning the first, the main SSEDPs' objective, as explained in Section 2.4, is reducing CO_2 emissions and the need for fossil-energy sources by combining various energy and non-energy measures. We also excluded from the co-benefits list the estimated monetary value of these savings, because they have already been deeply investigated through project assessment reports. The second criterion, positive meaning, excludes the undesirable co-impacts. Finally, project activities are interventions made in the *so-called* "hard" and "soft" domains in order to achieve project objectives. Hard domains are related to physical objects (e.g., buildings, energy plants, and grids), while "soft domains" address human capital, cooperative aspects, training activities, and awareness creation (Neirotti et al. 2014).

2.2.2   Step 2 - From raw list of co-benefits to a short selected list

After checking 36 projects websites and available official deliverables, plus related "sites & project" pages at Concerto initiative website and other previously cited materials, we obtained 156 expressions referring to positive impacts. Similar to Martin et al. (2014), the raw list was reviewed by a multidisciplinary research team, according to the co-benefits literature nomenclature and individual sensibility. More specifically, the work involved authors with different scientific backgrounds: three professional urban planners and one engineer (having active roles and experience in EU smart-city projects), and one academic with extensive experience in urban economics, project assessment, and appraisal methods. In this phase, we discarded too generic or unclear statements, merged closely related topics, and reworded them to provide short labels and clear definitions. To provide a scientific based taxonomy of SSEDPs co-benefits, in parallel with the specific analysis of projects, we went deeper into some major studies related to

energy efficiency policies (IEA 2014a), clean-energy policies (US EPA 2011), EU building-stock renovation scenarios (Copenhagen Economics 2012), and GHG mitigation policies (Davis et al. 2000). These four sources suggest as many dissimilar taxonomies, and they group the various benefits into different categories, ranging from five in IEA (2014a) and Copenhagen Economics (2012) to three in US EPA (2011). The whole picture obtained by merging these classifications, thus trying to simplify and avoid repetition, is shown below in Figure 2.
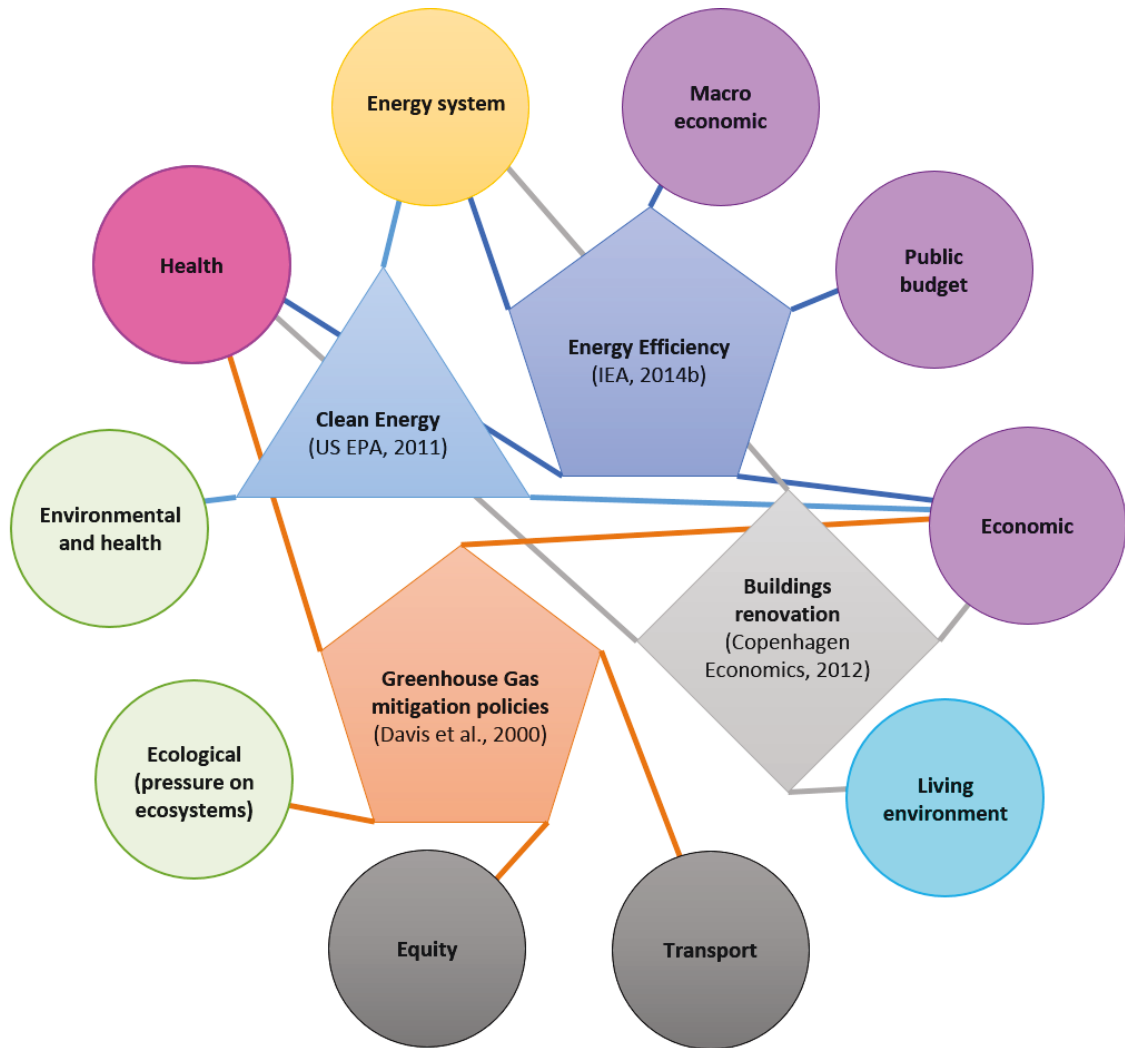
Figure 2: Combination of four different co-benefits taxonomies provided by reference studies

Some points of agreement emerge, although specific impacts and benefits are named under different labels. Not surprisingly, economic co-benefits are always recognized, as well as positive impacts on health, grouped with the environmental ones by US EPA (2011). Concerning economic impacts, a possible "change on employment and labor market" is expected by all studies, independent of their focus. Different emphasis is placed on how such co-benefits affect both public budgets and the social sphere, where

the first translates into new jobs with additional labor and corporate income taxes, and the latter into disposable incomes. Generally speaking, divergences arise mainly from placement of similar benefits under different categories. This brief overview confirms once again how overlapping topics and interlinkages are challenging in co-benefits' recognition and analysis, as highlighted in another recent study on this topic (Ürge-Vorsatz et al. 2016). Therefore to shed additional light on specific topics, we also reviewed sectorial studies approaching a particular perspective only, or considering in detail a small group of co-benefits. After a thorough and iterative comparison, we finally obtained a short list of 19 key urban potential co-benefits.

2.2.3   Step 3 - Classification by project activities

The SSEDP database has offered the starting point for a deeper analysis of 36 projects with comparable characteristics, such as funding schemes, geographical location, objectives, and the typology of involved stakeholders. In parallel to identification, and in the same iterative way, the list of main SSEDPs co-benefits has been organized with respect to the main groups of project activities, as defined in Section 2.3. To achieve this refinement, additional literature resources related to the "soft domains" of projects have been considered, such as (Campbell (2012); D'Albergo and Lefevre (2007); Lützkendorf et al. (2013a); Marika Roša and Federica (2013); Osuch et al. (2009); Pels and Maatje (2013). As a result, co-benefits are distributed among three main groups of project activities: (i) intervention on buildings and infrastructures at district level, (ii) actions on stakeholders, and (iii) design and management. Furthermore, for the first group, an additional distinction between direct co-benefits (i-a) and co-opportunities (i-b) has been noticed.

2.2.4   Step 4 – Introducing the smart-city perspective

As the last step of our investigation, we created a bridge between the co-benefits and the smart-city debate. Among other smart city development frameworks, we followed the conceptual and visual one provided by Mosannenzadeh and Vettorato (2014), suggesting seven components. A smart natural environment concerns mainly abiotic environmental resources. Under smart services, citizens' health and safety are grouped, while smart community deals with citizens' welfare and behaviors. Smart governance is related to administrative functions, as well as institutional roles and rules of the urban government. Smart economy relates to local economic activities, flows, and the labor market. Smart built environment encompasses physical and structural urban elements such as buildings, public spaces, and energy infrastructures. Finally, smart mobility and connectivity include

networks and systems enabling data exchange and people and freight movement. Following this framework, we assigned the co-benefits to the different smart-city components and delivered an improved graphical scheme.

2.3 Key findings and discussion

Linking the co-benefits literature with the SSEDPs investigation make possible the analysis of the projects under the co-benefits perspective. Going through the subsequent steps, we were able to reclassify SSEDPs' statements under a scientifically-based taxonomy. This Section reports the main findings of our investigation and how they fit into the existing smart-city debate.

As reported in Section 3.2, the analysis of 36 SSEDPs leads to the identification of 19 main urban co-benefits. To graphically report our results, we adopted a visual layout similar to those suggested by Khanna et al. (2014) in assessing low-carbon city initiatives. The following Fig. 3 provides a comprehensive overview of our findings, grouped into the categories defined in Section 3.3. Most recurring categories, shown in solid color black, are those occurring in at least half of the analyzed SSEDPs, while the less recurrent are indicated by a patterned fill.

This first result supports a positive answer to the question whether local co-benefits are expected as a consequence of SSEDPs implementation. Not surprisingly, by going through the labels, it clearly emerges how all the traditional sustainable development dimensions are covered: economic, social, and environmental. In particular, there is broad agreement about: positive effects on the local labor market, increased health and well-being of dwellings' occupants, and the creation of users' awareness of energy. Additionally, the result proves how a project assessment ignoring the "soft measures" not only leads to leaving aside at least four out 19 potential co-benefits but interestingly, some of the most often recurring categories.

Finally, it suggests that two-thirds of co-benefits, related to the physical intervention on buildings and energy networks, can be considered as direct consequences: i.e. cause and effect are strictly related and reported. The rest can be defined as co-opportunities, that, to trigger, there is a need for additional efforts outside the project activities or specific local conditions.

Numeber SSEDPs mentioning the co-benefit (Tot. = 36)

Co-benefits related to "hard measures"

Air quality — 4
Building life cycle cost — 4
Energy infrastructures resilience — 4
Energy supply chain — 10
Environmental resources management — 6
Fuel poverty — 9
Health and well-being — 13
Labour market — 17
Neighborhood identity — 7
Property value — 6

Co-opportunities related to "hard measures"

Energy services — 7
Loan conditions — 5
Tax revenues — 3
Technology development and deployment — 9
Territorial attractiveness — 10

Co-benefits related to actions on stakeholders

Professional skills — 11
Users awareness on energy-related issues — 16

Co-benefits related to project design and management

Decision making processes — 10
Institutional relationships and networks — 10

Figure 3: Comparison of common co-benefits and co-opportunities identified in SSEDPs. Those mentioned by at least half of the analyzed projects have solid fill

In the following sub-Sections, from 2.3.1 to 2.3.4, a brief description of each co-benefit is provided, with respect to scientific literature and SSEDPs. The projects acronyms are reported in capital letters.

2.3.1 Co-benefits related to intervention in buildings and infrastructures

Air quality

Air quality is related to changes in standard atmospheric composition due to the emissions of gasses and particulates near the Earth's surface, which can negatively affect human health, ecosystems, and building materials (World Health Organization. Regional Office for Europe 2000). Air quality improvement is recognized as a contemporary global challenge, due to the relevant economic costs to society (Timmermans et al. 2015). The additional contribution to an overall better air quality is explicitly mentioned by PLEEC, STEP-UP, CELSIUS, and SINFONIA projects. A reduction of other air pollutants is expected by shifting heat and power production from fossil fuels to renewables, or by decreasing energy demand through efficiency or passive design. Air-pollution-related impacts is a broadly investigated field; for deeper analysis, see (Bell et al. (2008); Joyce et al. (2013); Williams et al. (2012); Won Kim et al. (2003).

Building life-cycle cost

Large-scale interventions and integrated design make possible economies of scale for materials and services, and therefore a reduction of construction costs (CRRESCENDO). Besides, introducing renewable sources in buildings avoids electricity usage costs, referable to shared services, like common-spaces lighting or elevators operation. Moreover, according to IEA (2014a) and Ürge-Vorsatz et al. (2014), introducing efficient technologies in such systems reduces maintenance, repair, and operation costs (STACCATO, CLASS1, R2CITIES).

Energy infrastructures' resilience

Increasing energy-infrastructures' resilience includes the following aspects: a smart energy system may prevent peaks or damages and blackouts, by coupling predictive solution and metering systems with physical changes in the architecture and through diversification of supply systems and sources (SINFONIA). Additionally, power-grid benefits, due to producing electricity closer to consumers (ENERGY IN MINDS!), increased efficiency (TRANSFORM, CELSIUS,) and safety in energy systems (ENERGY IN MINDS! RENAISSANCE), are highlighted and recognized by SSEDPs and accessible in the literature (IEA 2014a; Schweitzer and Tonn 2002). In fact, the development of smart grids should also ensure the establishment of resilient and sustainable infrastructure solutions (Evans and Fox-Penner 2014), reducing the costs of breakdowns and the physical intervention of maintenance teams.

Energy supply-chain

The establishment of local energy supply-chain is achievable through new renewable plants, and also using already existing by-products: industrial waste heat (PITAGORAS, SINFONIA), agricultural or urban-sewage effluents (ENERGY IN MINDS!, GEOCOM), or urban waste. SSEDPs recognized this as a co-benefit, mainly due to additional income from energy sales and reduction of costs for by-products disposal. Moreover, specific land-use changes, like shifting from pasture to biomass production, as a fuel source, may lead to economic benefits (SERVE). Such local chains may result in a better local balance of payment, assuming the region retains the energy savings versus purchasing fuel externally (SERVE), and shifting energy generation from fossil to renewable sources could ensure long-term stability in fuel prices (SERVE).

Environmental resources management

Several SSEDPs' strives to increase environmental sustainability (CLASS1, R2CITIES) or reduce environmental impacts (ECO-CITY, ENERGY IN MINDS!, ECOSTILLER, STEEP), going beyond the purely energy-related aspects. For example, R2CITIES will contribute to reduced water consumption, sewage production, and construction waste, incorporating these aspects within the integrated buildings' design approach. Or ECOSTILLER will reduce the soil and aquifer pollution from livestock farming, due to the implementation of a very large-scale biomass energy plant. Overviews on green buildings economics are provided by (Eichholtz et al. 2010a; Hoffman and Henn 2008; Johnson Controls 2011), while the costs and benefits of the latter example are clearly reported in (IEA 2014).

Fuel poverty

Fuel poverty is usually defined as households' spending more than 10% of their income on homes heating to ensure indoor-thermal comfort (Howden-Chapman et al. 2012; Lewis et al. 2013; Marmot Review Team 2011). This phenomenon is also known as "heat or eat" (Ryan and Campbell 2012) and acknowledged even in developed countries: 12% of Western Europe households are living in fuel poverty (Lewis et al. 2013). Fuel poverty is mainly related to older uninsulated buildings as living places (Howden-Chapman et al. 2007; Marmot Review Team 2011) and to obsolete or inefficiently-operated district-heating networks (Tirado Herrero and Ürge-Vorsatz 2012). As an extreme consequence, it may lead to death, due to extremely cold homes in winter. Besides, heatwaves in the hot season are potentially fatal, mainly for children and aged people. The fuel-poverty issue has been approached by several SSEDPs (SORCER, STACCATO, SERVE, ECO-LIFE, ZENN, PLEEC, STEP-UP, TRANSFORM, CELSIUS) under different perspectives: e.g., SORCER suggested to revise energy contracting after building refurbishment, selling the heat needed at a contracted price, while SERVE determined statistically that, generally, the lower the income of the household, the higher the importance attributed to saving money. Fuel poverty is particularly relevant in the social-housing context, where energy costs consume a significant amount of the living budget (ECO-LIFE), and where the worst energy performances often exist due to the unaffordability of comprehensive renovations by low-income people (ZENN, PLEEC).

Health and well-being

The refurbishment of existing buildings or the construction of new ones, according to the latest energy-efficient technologies, coupled with high-quality materials and appropriate

design criteria, make possible better indoor living and working conditions. SSEDPs recognized several related aspects, such as increased daylight and visual comfort (CLASS1, ECO-CITY), better acoustic comfort (CLASS1, ECO-CITY, ENERGY IN MINDS!), improved thermal comfort (ACT2, ECO-CITY, ENERGY IN MINDS!, CLASS1, STACCATO, SERVE, SINFONIA, CITY-ZEN, CITY-FIELD, STEP-UP), reduction of cold homes (PLEEC), better spatial quality (ZENN), safety improvement (SERVE), the mental comfort of tenants (SERVE), and better indoor-air quality (ECO-CITY, ENERGY IN MINDS!, CLASS1, SERVE, PLEEC, R2CITIES). Empirical evidence and qualitative research support these statements (Acre and Wyckmans 2015; Aelenei et al. 2013; Jakob 2006). Recent studies (Howden-Chapman et al. 2012; Liddell and Morris 2010) have shown a correlation between improved envelope insulation and physical, as well mental, health benefits. According to (Copenhagen Economics 2012; IEA, 2014; US EPA 2011), better living conditions may also decrease public health and social expenditures (STEP-UP), and working in efficient buildings may increase labor productivity, thus producing the same effect as eliminating the energy expenditures (Lovins 2005).

Labor market

The direct impact on the local labor market of SSEDPs is mainly related to the implementation phase, and it widely varies due to some characteristics. One is the size of the intervention: how many buildings are refurbished or how large is the demonstration site. The second concerns the different approaches of physical intervention on buildings: Immendoerfer et al. (2014) recalled how the Buildings Performance Institute Europe (BPIE) exploring six different retrofitting approaches, with respect to their job-creation impact, have found that the highest would be for the "deep-retrofit" scenario (i.e. the one more concentrated in the design and construction, enabling the highest energy savings). Obviously, in spite of looking at employment opportunities provided at the national (Ürge-Vorsatz et al. 2010), international (Joyce et al. 2013), or global level (IEA, 2014a), projects are solely focused on the narrow dimension. SSEDPs are looking at the involvement of local handcrafts in the construction activities (RENAISSANCE), or at local business benefits (SOLUTIONS) and opportunities (ECOSTILER) generated by investments remaining within the local economy (SERVE). In this regard, also new full-time equivalent (FTE) positions for planning and management of the projects are explicitly mentioned (TETRAENER, SORCER) and reported: e.g., five–eight FTE person-year (SOLUTION). Other projects (SESAC, CLASS1, CONCERTO AL PIANO, GREEN SOLAR CITIES, SEMS, ECO-LIFE, SOLUTION, and TRANSFORM) report the establishment of new

green jobs or green innovative companies: e.g., five–ten permanent new positions created in an HRV-firm (GREEN SOLAR CITIES).

Neighborhood identity

The neighborhood quality comprises several dimensions such as the economic status of inhabitants, the quality of the housing stock, the concentration of social housing, and the social mix (Newman and Schnare 2010). The district approach that characterizes the SSEDPs, as opposed to single-building interventions, enables the creation of a better image for the neighborhood (ECO-CITY, GREEN SOLAR CITIES, SOLUTION, and EU-GUGLE) and upgrading the living area/community (SOLUTION). This results particularly in contexts that have lost, or never had, their own identity previously, like for some demo sites (REMININ-LOWEX, ECO-LIFE). The foundation of a new identity, for example, is provided by the use of abandoned mines for new energy, as physical a manifestation of the transition from black to green energy (REMININ-LOWEX), or by a former "ghetto" becoming a CO_2 neutral neighborhood, introducing another way of living and building (ECO-LIFE). Such situations are supported by OECD (2001, pg.40), proclaiming that an *"investment in individual and group identity can lead to the creation of dense social networks and ultimately better economic and social outcomes"*. This is a cross-cutting co-benefit, often involving effects on both physical elements and stakeholders. If the latter are missing, this is likely to be more of a co-opportunity.

Property value

One of the main domains of intervention in SSEDPs is the building sector. Refurbished buildings, with an integration of renewables and energy-efficient appliances, achieving better energy performances, have an increased expected value on the market. This has been seen especially in older residential buildings, although with large variability across various territorial contexts and countries (Bonifaci and Copiello 2015; De Ayala et al. 2016; Popescu et al. 2012). Indeed, such an increase in the property value is expected at the neighborhood level within SSEDP's demonstration sites (ECO-CITY, RENAISSANCE, CLASS1, and R2CITIES). The overall property value may also increase due to *cubature bonus* obtained by better energy performance achievement: i.e. enlargement of an existing building may lead to the creation of new apartments to rent or sell to finance interventions (SINFONIA). It is worth mentioning that, on the contrary, one project (ZENN) casts doubt about a positive market appreciation of renovated buildings, if compared with intervention costs. Moreover, renovated energy infrastructures will increase the asset value for their owner, regardless if private or public.

2.3.2   <u>Co-opportunities related to intervention on buildings and infrastructures</u>

Energy services

The neighborhood approach can make energy-efficiency improvements financed by contracting or energy-service companies (ESCOs) more viable (Immendoerfer et al. 2014); therefore, establishment or testing of ESCOs is mentioned in several SSEDPs (RENAISSANCE, PIME'S, SESAC, ENERGY IN MINDS!). Large-scale intervention with multiple implementable measures may offer better conditions, due to the dimension of the intervention itself and the variety of room for improvement in different contexts. For instance, some SSEDPs report that a new type of public tendering and negotiation processes has been activated, based on fulfillment of energy and technological performance requirements (SESAC) or new energy schemes implemented (CONCERTO AL PIANO). In Delft (SESAC), an ESCO has been established to build and operate the new district- heating network through a call for tender to private investors. Innovative energy services, as mentioned by the IEA (2014), may be alternately a co-benefit or a co-opportunity, depending on whether its development is inside or outside the project activities.

Loan conditions

Several experiences with SSEDPs indicate that large-scale interventions are interesting for banks. Selecting lenders through public tenders may result in better loan conditions: a lower interest (STACCATO) makes possible longer debt-payback periods and/or more affordable payments. In other cases, shorter payback periods, due to EU funding, increase the profitability of the investment in renewable sources and energy efficiency (GREEN SOLAR CITIES), attracting a relevant local investment (HOLISTIC) or the interest from foreign investors in close to the border communities (SORCER). Again, enabling access to a sustainable housing market (R2CITIES) can be achieved through soft loans for renovation or green-building loans with special financing conditions (Hoffman and Henn 2008). This is particularly relevant in overcoming financial barriers to such investments, characterized by necessary upfront investment costs (Ryszard et al. 2010).

Tax revenues

Increasing local tax revenues has been highlighted as a theoretical benefit by a couple of SSEDPs (SERVE, STEP-UP). Another project (SEMS) has tried to quantify it: a total investment of €47 million during the five years of the project is reported as generating a

turnover of €7.5 million, equally divided by the local regional level and the federal government (Immendoerfer et al. 2014). Although the topic is poorly investigated by project and at the urban scale, similar to job creation, the potential positive fiscal impact of implementing energy-efficiency measures is acknowledged (IEA 2014a). Copenhagen Economics (2012) estimated the values related to different scenarios for European building-stock renovation. Other studies are country specific, such as a German one, finding that each euro spent by the central government for energy-efficiency refurbishment of buildings, generates revenue of approximately €2–5 additional tax revenue and social security contributions, including avoided unemployment costs (Kuckshinrichs et al. 2013). Significant differences between the tax systems of countries suggest generally to consider this, on the grounds of prudence, as a co-opportunity.

Technology development and deployment

SSEDPs are, by definition, deputed to introduce or to test cross-cutting technologies in the real world by large-scale demonstration activities. Playing a pioneering role with respect to other districts and cities (ECO-LIFE), they foster the implementation of just-tested technologies and their diffusion at the urban level. Moreover, they offer references as case studies for contractors, developers, and designers (ECO-LIFE) and help to improve the local know-how on innovative energy technologies and systems, from a theoretical, as well as practical, point of view. Consequently, the involved enterprises are active in R&D (SESAC) and often are frontrunners in the adoption of innovative energy-efficient solutions (Davis et al. 2000; IEA 2014). Indeed, additional purposes declared by SSEDPs are to foster the marketability of technologies (CRRESCENDO, ECOSTILER, and TRANSFORM) and to improve the connection of the social needs of building-users with innovative market actors (EU-GUGLE). This may lead to new commercial links that enable cross-cutting energy technologies to compete in new ways, enlarging the client list or designing new supply-chains (R2CITIES).

Territorial attractiveness

Several SSEDPs recognize the importance of developing tailored territorial marketing, organizing visits to their demonstration sites (ACT2, ECOSTILER, SEMS, ECO-LIFE, and SOLUTION) and achieving international-media exposure, as for example, Grenoble's De Bonne neighborhood (SESAC), which became recognizable at the national level after winning the first National "Eco-district" Prize in 2009. Similarly, in Germany, the Weilerbach district (SEMS) is now well-known nationwide and the Kortrijk CO_2 neutral neighborhood, located in the Flemish province West Flanders (ECO-LIFE), got attention

at national and international levels, due to its high-quality sustainable buildings for rental social housing. Those responsible for the project frequently receive requests to give lectures, and it became a case study pointed out as an example for other municipalities interested in approaching an energy-transition process. This is why city-to-city exchange is rated by public officers as the one with a higher impact rate, among the various learning opportunities and, on the global level, expenditure for study tours could be estimated in the range of US$100 million per year (Campbell 2012). According to collected examples, an increase in the urban appeal is also expected to attract new households, business activities, and green tourism. However, to be fully exploited, additional efforts beyond the project activities are usually needed. Therefore, this is likely to be considered as a co-opportunity, requiring the establishment of a proper agency to be exploited (D'Albergo and Lefevre 2007).

2.3.3 Co-benefits related to actions by stakeholders

Professional skills

Providing training activities to professionals involved in SSEDPs (e.g., architects and engineers), or practitioners (e.g., building workers and craftsmen), increases their knowledge and know-how on innovative processes and energy technologies (SOLUTIONS), like the hydrothermal-networks design (TETRAENER) or energy-monitoring devices (ECO-LIFE). This improves the effectiveness of their work, productivity, and competitiveness on the labor market. Although many SSEDPs foresee training activities (ACT2, ECOSTILER, RENAISSANCE, SESAC, GREEN SOLAR CITIES, HOLISTIC, SOLUTION, R2CITIES, CITYFIELD), their magnitudes widely vary, as, for example, ranging from six installers and two representatives of property management (HOLISTIC) to 500 persons among the professional audience (GREEN SOLAR CITIES). The importance to have highly skilled workers and professionals for an effective execution of deep building-stock ep renovation scenarios is also stated and specifically investigated in a study by Ürge-Vorsatz et al. (2010).

User awareness on energy-related issues

Studies on barriers to energy-efficiency (Sorrell et al., 2004) or to renewable-sources penetration (Painuly, 2001) mention poor knowledge of the product, resistance to change, and inadequate or imperfect information as important barriers. To overcome these barriers, an active engagement of end-users that encourages and enables their exchange of experiences, expertise, and viewpoints is needed. With respect to this point, promoting

knowledge based on practical tests and stimulating familiarity with technologies decrease bias against them. Similarly, reliable and trustworthy information increase acceptance of implemented measures and stimulates behavioral changes. The relevance of users' awareness emerged recently in a monitoring campaign in Italy; looking at a highly energy-efficient neighborhood, Castagna and Antoniucci (2015) concluded that the performance of buildings with complex systems, like HAVAC, seem to be even more negatively affected by inappropriate occupants' behaviors. Another U.K. study in this field estimates a variance of 51% in heat and 37% in electricity consumption attributable to human factors (Gill et al. 2010). Therefore, SSEDPs often undertook several actions in this field (ACT2, ECOSTILER, SORCER, ECO-LIFE, SOLUTIONS, CELSIUS, CITYFIELD) to improve stakeholders' awareness through educational activities and to increase acceptance of implemented measures (e.g., about 200 people were reached within courses and information evenings organized by the SOLUTION project, while 75 were involved in smart-metering testing and 230 answered to bespoke surveys). Other projects, after effective stakeholders' engagement, report a positive change in residents' energy behaviors (CRRESCENDO, ECO-CITY) or an increased positive attitude towards, and acceptance of, efficiency and renewable sources (CRRESCENDO, CONCERTO AL PIANO, SOLUTION, TRANSFORM).

2.3.4 Co-benefits related to project's design and management

Decision-making processes

Participating in an SSEDP promotes and enables the exchange of experiences, introduces innovation in processes, and often imposes on partners the fulfillment of new quality and management requirements. Statements gathered from projects' analysis in this field provide an extensive and articulated list. Some aspects are related mainly to the positive impacts generated by the interaction among different parties. For example, a qualitative improvement of undertaken measures arises from the effective exchange of experiences, field visits, and training within the project consortium (ENERGY IN MINDS!, RENAISSANCE, GREEN SOLAR CITIES, EU-GUGLE, and READY). Others are related to changes in the way of participating: for instance, developing new innovative procedures; integrating architects, engineers, and policy makers (TETRAENER); improving joint activities involving city planners, researchers on technology, and citizens' representative (PLEEC); or even bringing operational plans to the strategic level and changing cities strategies from business-as-usual to low–carbon- driven (TRANSFORM). Peer-to-peer learning is often identified by project partners as fundamental tools to learn

from each other and to discover blind spots in procedures (Marika Roša and Federica 2013). Project's partners' qualification (ECO-LIFE) and improvement in decision-making processes (CRRESCENDO) can also be seen as a human-capital benefit (Dagum 2006; Nosvelli 2009); therefore, having access to cognitive resources and being involved in policy solutions to urban issues are widely considered by projects (D'Albergo and Lefevre 2007). An SSEDP can act as a driver, boosting people's intrinsic motivation and supporting creativity (Conti and Amabile 1999); however, a permanent positive effect requires additional efforts. Therefore a durable innovation should be considered as a co-opportunity.

Institutional relationships and networks

Institutional relationships and network establishment within a single SSEDPs offers the opportunity to learn and adapt experiences from other cities and partners (STEP-UP). Moreover, increased awareness (SOLUTION) and clustered activities and joint events and exchange of best practices (EU-GUGLE, R2CITIES, ZENN, CELSIUS, STEP-UP), due to co-operation with other energy-related EU projects, may lead to additional funding opportunities and local development. Capitalizing the knowledge of working with EU projects developed by actors involved (SOLUTION) gives the chance of major competitive advantages in next calls for funding (Franceschetti et al. 2015). The relevance of being part of broad networks is acknowledged by SSEDPs, as was by the joint activities done under the so-called "MySmartCityDistrict" group, involving eight of them (see: mysmartcitydistrict.eu). Cooperation with transnational partners is often considered an added value of these projects; however, it should be promptly defined and targeted in the planning phase, and not thought of as a nice to have side effect (Osuch et al. 2009).

2.3.5   Urban co-benefits under the smart-city perspective

To conclude our research, we moved from the co-benefit list of Fig. 3 to a graphic representation, suggesting the contribution of SSEDPs' towards the achievement of smart-city status. In Fig. 4, an innovative overview on the importance and potential positive impacts of such projects in the overall urban transition, as well as on each specific smart-city component, is given.
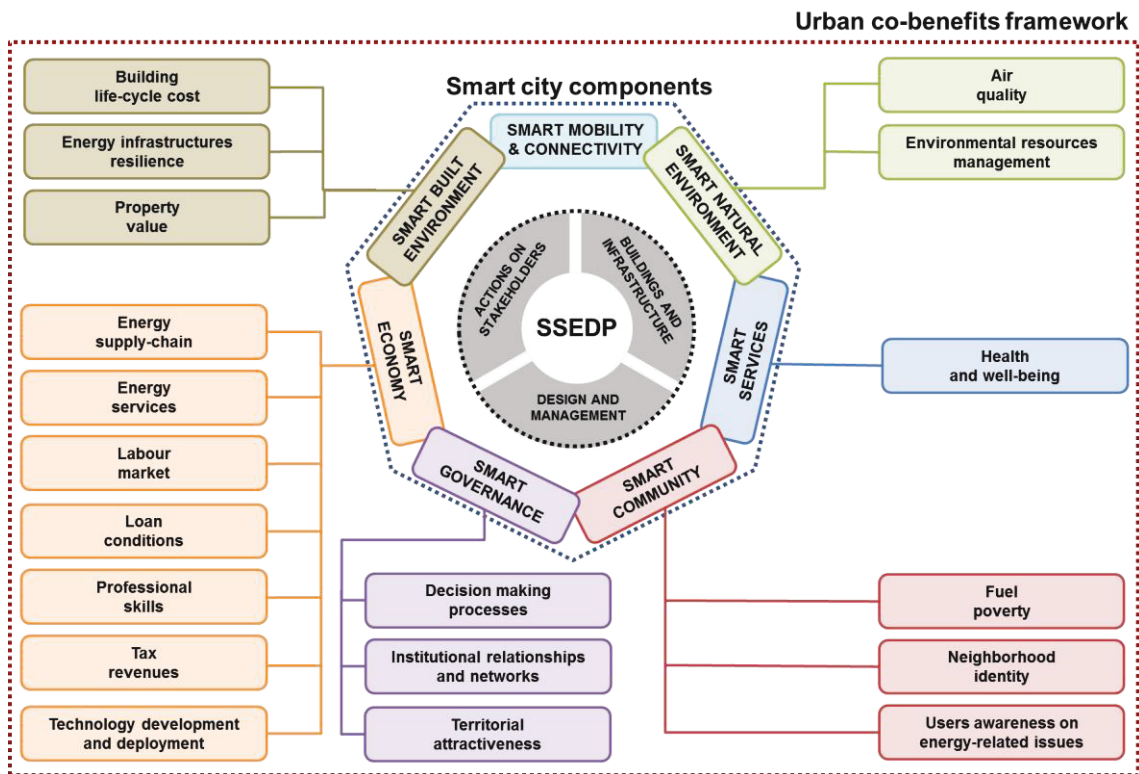
Figure 4: Role of SSEDPs co-benefits towards the achievement of smart-city status

At first glance, it is apparent how co-benefits are expected in each component, with a predominance in smart economy and with the exception of smart mobility. The first leads to the consideration that several co-benefits should be easy to monetize through market- or shadow-price methods (Ürge-Vorsatz et al. 2014); therefore, the main issue probably concerns the definition of proper indicators and the measurement variation between ex-ante and ex-post projects' implementation. The latter results are mainly attributable to the characteristics of investigated projects: on one hand, Concerto projects were basically focused on buildings and energy networks; therefore, the consideration of mobility issues was left aside. On the other hand, the Smart City and Communities—those in some cases address the clean mobility challenges (e.g., SINFONIA foresees charging stations for electric vehicles and smart points for traffic management) —are in a too-early stage to provide enough clear information, and they have not yet reported practical results.

Smart community, smart governance and smart built environment, having three co-benefits each one are well represented, although some co-benefits, mainly related to human capital improvement and stakeholders' relationships are challenging to measure and to be quantitatively framed. Nevertheless, some methods are available, as it will be further discussed in the next Chapter 3 of the thesis, and implemented in practice in Chapter 4, with regard to property value.

The smart natural environment presents two co-benefits that should be approached not only from a quantitative point but also from a spatial perspective because they are related to flows of environmental resources, as well as their geographical distribution. The latter is particularly relevant for pollutant emissions, i.e. those, although measurable at a given point, that also spread through air or soil.

The last component, smart services, has only one co-benefit, named health and well-being. However, this encompasses a multitude of positive mental, as well as physical, effects on occupants. Therefore, to grasp its full potential, it should be framed through multiple indicators. A broad review of the scientific literature in this field may help the project evaluator in choosing the most representative and relevant assessment methodologies: in Chapter 5, an example of multi-criteria analysis (applied to deep energy retrofitting of buildings) one is offered to investigate, among others, the interest of homeowners in an increase in health and well-being.

Results obtained show how relevant is or is likely to be, the contribution of these projects in the majority of the various smart-city components. Therefore, a proper assessment of co-benefits is crucial to really appreciate their value, besides only their contributions to reducing energy demand and CO_2 emissions and increasing the use of renewable-energy sources. In particular, the most recurrent expected effects are the creation of new jobs related to projects' implementation, the increase in energy and environmental awareness among stakeholders, and better health and well-being of occupants due to the improved indoor conditions in their refurbished dwellings.

Moreover, this first step of the research shows how the role played by the so-called "soft measures" is acknowledged as relevant in co-benefits creation. Therefore, appropriate indicators and assessment methodologies should be adopted to measure the value of the tangible and intangible assets created by the project and to compare alternatives.

Chapter 3 - Economic assessment methodologies

Policies, programs, and projects are usually designed to deliver one or more specific desired changes (outcomes), through the development and completion of certain measures and activities (outputs). Positive changes are intended as benefits by people or organization (stakeholders) affected by outcomes. Furthermore, the achievement of the project's outputs may lead, whether intentionally or not, to other additional positive impacts (co-benefits), or conversely to negative changes (co-costs). The concept of co-benefits, related to the low-carbon sector, emerged beginning in the early 1990s in parallel with the release of the first IPCC assessment report on climate change (Davis et al. 2000). Nowadays, the relevance of incorporating co-benefits into the decision-making process, to attain a better grasp of the total welfare value of foreseen or applied policies, is recognized and supported globally by several notable organizations (IEA 2014a; Pachauri and Meyer 2014; US EPA 2011).

Nevertheless, given the complexity of gaining a complete picture and clear understanding of the interrelationships, rebound (Alcott, 2005) or cascade effects, co-benefits are often analyzed by sector within the various branches of science, e.g., medicine or environmental sciences. One of the most investigated sectors concerns the co-benefits of policies for the mitigation of greenhouse gasses (GHG) (Davis et al. 2000), where the widely investigated co-benefits are human health, industrial productivity, poverty alleviation, and job growth (Ürge-Vorsatz et al. 2014).

Conversely, those related to projects primarily aimed at reducing GHG emissions within the urban environment, by achieving relevant energy saving in buildings, are mostly qualitatively measured and seldom monetized. For example, since the early experiences in devising and implementing the European Union (EU) initiative CONCERTO, it has been well recognized that the district approach of such projects could provide additional relevant positive impacts (Di Nucci and Spitzbart 2010; Lützkendorf et al. 2013b). In parallel, the relevance of improving the understanding of co-benefits by decision makers (Immendoerfer et al. 2014) began to be clear and therefore the value of properly evaluating the increase in people´s welfare that arises from such projects. Actually, there still is a need to optimize the level of discourse and to attribute to co-benefits their full title

within the quantitative decision-making framework, because in such projects, "the absence of co-impacts (co-benefits and adverse side effects) is probably the exception much more than the rule" (Ürge-Vorsatz et al, 2014).

Starting from these premises, this Chapter aims to provide an overview on suitable methodologies for economic assessment, creating a framework for evaluating the key urban co-benefits recognized by Smart and Sustainable Energy-District Projects (SSEDPs) funded by the EU.

This Chapter is organized as follows: Section 1 provides a brief exposition of the fundamentals of cost-benefit analysis. In Section 2, the starting point of the research is briefly recalled, and in Section 3 the research methodology is illustrated. Section 4 provides the synthetic result of the investigation into co-benefit assessment methodologies; here also shortcomings and further steps are analyzed and discussed.

3.1 Rationale for cost-benefit analysis

According to the Kaldor-Hicks criteria (Hanley et al. 2009), when evaluating public policies, a decision maker should assess the delivered changes to people´s welfare, and then choose the one expected to deliver the higher welfare increase. For this reason, including not only the main outcomes but also the co-benefits within this assessment, makes possible better identification of the welfare outcomes of various programs and projects. The most common tool for welfare evaluation in applied economics is cost-benefit analysis (CBA), through which all the costs and benefits of a project are compared in order to estimate its net benefit (Pearce et al. 2006). This tool is applied both in the private and in public sectors; in the second case, it is sometimes called social CBA, because it aims at evaluating costs and benefits for the entire society (Ürge-Vorsatz et al. 2014). The CBA is applied to the decision-making framework by quantifying, in monetary terms, all the positive effects (benefits, or inflow), as well as the negative (costs, or outflow), and then calculating the Net Present Value (NPV). The formula is:

$$\text{NPV}(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Equation 1: Net Present Value

where t is the time of the cash flow; i the discount rate applied (often selected as the expected return, per unit of time, on an investment with similar degree of risk); R_t the net cash flow (benefits minus costs) at each time t; and N is the total number of periods involved in the calculation. If the NPV value is positive, then the project is said to be

welfare increasing. Other feasibility calculations, typically adopted for building-retrofitting projects, are the Internal Rate of Return (IRR) or the Discounted Payback Period (DPBP) (Boeri et al., 2011).

A critical shortcoming of such analysis is that not all co-benefits are directly evaluated in monetary terms, so non-market techniques have to be applied to price them. Such techniques investigate the consumer preferences starting from individual purchasing habits (revealed preferences) or asking them directly their preferences (stated preferences). Whenever original studies are unaffordable, as often occurs in policy analysis, "taking economic values from one (geographical) context and applying them to another" (Pearce et al. 2006) may be the second best option (benefit transfer). Together with the cited methods, there is also a family of evaluation techniques called "non-demand approaches", based on the calculation of the costs. The idea behind these techniques is that, if people are willing to cover some costs for a non-market good, e.g., to improve the environmental quality of a site, then the site has at least the same worth as the sustained cost. Multiple techniques are available, such as market prices approaches, opportunity costs, replacement costs, and defensive expenditures; for a detailed description of these methods, see Bateman and Turner (1993). Although widely applied in practice, non-demand approaches are seldom criticized by economists, because they only approximate the value and are not capable of really describing the welfare change provided by the non-market good in question. Despite such criticism, non-demand approaches may be used to demonstrate the importance of some non-market goods and services.

A second critical aspect emerges mainly because people are often doubtful in pricing goods and services that are considered to be priceless. In particular, in the health sector, it is quite inconvenient and maybe even unethical to give a price to human lives and the status of their health. In the environmental field, opponents of non-market methods argue that trying to place a price on nature may encourage equalizing environmental services with artificial substitutes, thus leading to a degradation of the environmental quality. Moreover, people´s preferences for some environmental goods may not reflect their ecosystem importance, but simply be related to the common perception (for this reason, often, conservation projects promote themselves through attractive "flagship" or "umbrella" species, like the Panda bear or elephant, rather than protect less appealing species).

Nevertheless, non-market valuation is broadly applied because it is the only solution to assess welfare changes in a comprehensive way. In addition, methodologies have been studied for many years in order to reduce potential biases, and currently the procedures and estimates are widely accepted in economics. In any case, regardless of the methods

chosen, it should be remembered that CBA is "about value, rather than money". Money is simply a common unit that, as such, is a useful and widely accepted way of conveying value" (Nicholls et al. 2012). Indeed, CBA applied to SSEDPs must necessarily translate welfare changes into money, because this is a tool to make explicit and facilitate the debate, and not because the final aim is to monetize everything.

3.2 Families of monetization techniques

The welfare changes analyzed here are those related to the execution of Smart and Sustainable Energy-District Projects (SSEDPs), as defined in the previous Chapter 3 of the thesis. Starting from the key urban co-benefits list and framework (see Section 3.3.), the various techniques are analyzed, aiming at identifying the most appropriate with respect to targeted stakeholders and expected outcomes. In the discourse, both CO_2-emission reduction and the energy savings are not considered because they are the primary SSEDPs goals, precisely measured and stated by each project. They can be easily translated into values, according to current energy and carbon prices, although also these values may be substantially unexplained or have considerably changed over time or between countries. For example, EU ETS allowance ranged from 30 €/tCO_2 in mid-2008 to less than to 5 €/t CO_2 in mid-2013 (Koch et al. 2014), while energy prices widely differed across member States (e.g., from close to 12 €c/kWh including taxes in Sweden to less than 3 €c/kWh in Romania in 2012) (European Commission 2014d).

A literature review was conducted to identify the most appropriate indicators, capable of capturing each of the 19 detected co-benefits. According to (OECD, 2003), an indicator is defined as "a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value": i.e. selection of appropriate indicators enables the reduction in the number of measurements necessary to precisely describe a situation (OECD 2003). Common indicators on well-being are suggested by OECD (2011), and, more specifically for the assessment of cooperation programs by the EU (2013). Other detailed qualitative and quantitative indicators, adopted for the measurement of socio-economic and environmental performances of SSEDPs, are found in Di Nucci and Spitzbart (2010) and, additional ones related to technical aspects, in Lützkendorf et al. (2013b). Moreover, Ürge-Vorsatz et al.(2014) provide a useful list of physical indicators based on a recent review of approaches to the measurement of climate-change mitigation co-impacts. Co-benefits from energy efficiency, the exploitation of clean-energy sources, or GHG mitigation

policies are often investigated singly or by specific area. Therefore, several studies covering the main groups of SSEDPs' activities were analyzed. They are reporting positive impacts on:

- air quality (Bell et al. 2008; Chau, Hui, and Tse 2008; Chau, Tse, and Chung 2010; Joyce, Bo Hansen, and Naess-Schmidt 2013; Williams et al. 2012; Won Kim, Phipps, and Anselin 2003);

- property value (Bonifaci and Copiello 2015; Chapman et al. 2009; Deng, Li, and Quigley 2012; Eichholtz, Kok, and Quigley 2010; Fuerst and McAllister 2009; Hoffman and Henn 2008; Howden-Chapman et al. 2012; Johnson Controls 2011; Popescu et al. 2012);

- energy infrastructure resilience (Schweitzer and Tonn 2002);

- tax revenues (Joyce, Bo Hansen, and Naess-Schmidt 2013);

- jobs and investments (Janssen and Staniaszek 2012; Joyce, Bo Hansen, and Naess-Schmidt 2013; Tirado Herrero et al. 2011; UNEP/ILO/IOE/ITUC 2008; Ürge-Vorsatz et al. 2010),

- fuel poverty (Bone et al. 2010; Tirado Herrero et al. 2011; Ürge-Vorsatz et al. 2010; Williams et al. 2012),

- environmental resources management (IEA 2014a, 2014b);

- stakeholders' skills and awareness (Borgatti, S.P., Candace 1998; Brandon and Lewis 1999; EEA 2013; Gill et al. 2010; Hori et al. 2013; Khandker, Koolwal, and Samal 2010; Lewis, Ní Hógáin, and Borghi 2013; Painuly 2001; Rae and Bradley 2012; Sorrell et al. 2004; van Beurden 2011);

- neighborhood quality and urban appeal (Campbell 2012; Lee 2008).

Some of these researchers approach a specific topic by different perspectives: e.g., Won Kim, Phipps, and Anselin (2003) translate the benefits of reduced air pollution in the Seoul metropolitan area as an increase in residential property value, while Pollicino and Maddison (2001) estimate the cost of air pollution as a damage to buildings. Differently, Bell et al. (2008) consider the benefits of improvements in outdoor-air quality from the perspective of human health, while Chau, Hui, and Tse (2008) consider those derived from improving indoor air-quality.

The works of other authors, such as Joyce et al. (2013) or Tirado Herrero et al. (2011), cover the multiple benefits from sectoral interventions. For example, the first relates the energy-efficient renovations of the buildings in the EU to energy savings, job creations, tax revenues, health benefits, and air pollution. The second quantifies the implications of employment, energy security, and fuel poverty arising from retrofitting the Hungarian building stock. Additional references are used to explain the importance of social and

human capital (HC) in measuring a project's co-benefits (Borgatti and Candace 1998; Franceschetti et al. 2015; Jones et al. 2009; Krishna and Shrader 2000; OECD 2001). In particular, Dagum (2006) analyzes three different methods of estimating the monetary value of HC: (i) prospective, (ii) retrospective, and (iii) latent variable-actuarial (LV-A). Also, a literature review of measurement methodologies and monetization methods is found in Nosvelli (2009).

On the basis of such references, we suggested which economic assessment methodologies are applicable to translating measured co-benefits into economic values. Generally speaking, co-benefit monetization is possible by employing several techniques that are related to specific categories: existing market analysis, revealed preferences, stated preferences, and transferring results. The first existing market is applicable when a direct data collection of market prices of goods or services and close substitutes of goods or services can be eventually adjusted for distortionary factors (so-called shadow prices). Another market-based technique is the cost of illness (COI), even if it is slightly different from the direct market-price approach. COI aims at estimating the amount of cost caused by a disease or the net gain that could be obtained if the disease is eradicated. The others are techniques used in the economic literature to evaluate non-market goods. Table 1 provides an overview of the various typologies of non-market techniques.

In particular, revealed-preference methods assess the economic value of a good or service through market data, using the consumer surplus (CS) for that good or services as a measure of welfare change (Champ et al. 2003). The two most common techniques in this framework are the travel-cost method and the hedonic price. Travel cost is usually applied for the value of recreation since it derives the value of a site by assessing the number of trips and the distances traveled by tourists. The hedonic price method assumes that the value of a good is given by its characteristics, so the objective is to decompose the good into its relevant characteristics and evaluate them separately (an operational implementation of this method to property values estimation is offered in Chapter 5 of this thesis).

Group	Typology	Technique	Welfare measures
Indirect methods	Revealed preferences	Travel cost (TC)	Consumer surplus (CS)
	Revealed Preferences	Hedonic price method (HPM)	Consumer surplus (CS)
Direct methods	Stated Preferences	Contingent valuation method (CVM)	Willingness to pay (WTP) Willingness to accept (WTA)
	Stated Preferences	Choice experiment (CE)	Compensating variation (CV) Equivalent variation (EV)
Second Best	Stated/Revealed preferences	Benefit Transfer (BT) Value Function Transfer	Consumer surplus (CS) Compensating variation (CV) Equivalent variation (EV)

Table 1: Non-market evaluation techniques.

When market data are not available, welfare changes may be estimated through stated-preferences methods, applied by creating a hypothetical scenario and asking people how they would behave if that scenario were real (Champ, Boyle, and Brown 2003). Contingent valuation (CVM) and choice experiments (CE) are the methods used for this purpose. CVM is carried out creating a scenario and asking people their willingness to pay (WTP) or to accept (WTA) a compensation for that scenario (Mitchell and Carson 1989). On the other hand, CEs are based on the characteristics theory of value (Hanley, Barbier, and Barbier 2009). The good or services are decomposed into their attributes and each attribute is associated with several levels. The combination of attributes and levels create multiple scenarios that are proposed to respondents iteratively. Within the stated-preferences context, welfare changes are estimated through two different measures: compensating variation (CV) and compensating variation (EV). CV is the maximum amount of money that people are willing to pay for an increase in the level of that good or service. EV is the minimum amount of money people would accept as compensation for a lower level of provision of that good or service. In Bisello and Grilli (2016) is reported an operational implementation of this method, i.e. to estimate the value of the new infrastructure for urban information foreseen by the SINFONIA project.

A second-best approach to non-market valuation is the benefit transfer (BT) or value-function-transfer method, through which the value of a good is derived by analyzing similar studies carried out in various contexts and transferring the welfare measure (Boyle and Bergstrom 1992; Navrud and Ready 2007). The choice of the technique for valuing non-market goods depends on the nature of the good itself, as well as on the suitability of the approach to understanding the nature of the benefit flow (tangible or not tangible, use or non-use value).

Through the application of these techniques, we argued it is feasible to incorporate co-benefits into a broad CBA of an SSEDP, making clear to the wide public how relevant welfare changes are, and what they are worth. Examples of how a cost-benefit assessment is heavily influenced when taking into account also some intangible benefits, for instance, measuring the social return of investments (Nicholls et al. 2012), are already available. Similarly, the vastness of the co-benefit concepts, beyond the traditional notion of "externality", is well-known, at least in the debate about climate and energy policies (Ürge-Vorsatz et al. 2014).

3.3 Indicators and methodologies for co-benefits assessment

Linking co-benefits with indicators and techniques for monetization has been done through the review of literature mentioned in Sect. 4 and the elicitation of experts' knowledge (Ford and Sterman 1997). Five brainstorming sessions took place between September and October 2015, bringing together an urban planner, an environmental economist, and a sociologist to share and debate findings.

As result of our investigation, we linked each co-benefit with one or more indicators and techniques that are able to provide us with a monetary measurement of expected welfare changes. References to the existing literature enabled us to define at least one evaluation indicator for each co-benefit. In a few cases (specifically: users awareness on energy issues, loans conditions, and assets value), we detected multiple options and related assessment methodologies. Concerning monetization techniques and approaches, we have been able to discern three different quality levels of the information. The best concern studies suggesting monetary estimations of the co-benefit magnitude. An intermediate level deals with references pointing out methodologies used for the economic assessment of a specific co-benefit (or one of its relevant details). The lowest includes estimations or approaches suggested by the authors by analogy to reference literature, i.e. we found a confirmation of the possibility to assign an economic value to the co-benefit, but a specific study on this topic hasn't found during this investigation stage.

3.3.1 Smart natural environment co-benefits

Air quality

Reference(s)	Indicators	Techniques	Figures
(Di Nucci and Spitzbart, 2010) (Bell et al., 2008) (Joyce et al., 2013) (Williams et al. 2012)	Pollutant concentration (SO2, NOx, and PM)	cost of illness (COI) quality-adjusted life year (QALY) value of a statistical life (VSL)	4 to 6 billion EUR health benefits from air pollution decrease, achievable through the retrofitting of EU building stock and related energy-consumption reduction (Joyce et al. 2013)
(Aunan et al., 2004; Tidblad et al., 2012; Ürge-Vorsatz et al. 2014)	Damages to building materials	CV: WTP for cleaning and restoration	annual damage to the cultural monument valued between £0.4m and £0.6m in Lincolnshire (Pollicino and Maddison 2001)

Although the health impacts of urban air pollution are one of the most investigated co-benefits (Williams et al. 2012), and multiple studies provide strong evidence about their economic relevance (Bell et al. 2008), they remain underestimated, due to other unquantified or underestimated endpoints

Environmental resource management

Reference(s)	Indicators	Techniques	Figures
Deng, Li, and Quigley (2012) Hoffman and Henn (2008)	Water consumption in buildings	HPM to estimate water-efficiency value Market or shadow prices	NPV over a 20-year life cycle equal to US $0.51/sq. ft. for reduced water use in green buildings.
(Johnson Controls, 2011) Eichholtz at al. (2010)	Sewage production in buildings	Market or shadow prices	Water, wastewater, and energy expenditures are around -10% to -30% lower in ENERGY STAR certified buildings

We also argue that a CV could be applied to estimate the willingness to pay for reducing impacts on environmental resources, although Hoffman and Henn (2008) point out that, despite the measurable benefits, individuals' perception of green buildings is affected by cognitive biases that negatively impact their awareness of environmental impacts.

3.3.2   Smart services co-benefits

Health and the well-being of occupants

Reference(s)	Indicators	Techniques	Figures
(Jakob 2006). Joyce et al. 2013) Bell et al. (2008) and Williams et al. (2012). Chapman et al. (2009)	Number of visits to general practitioners, hospitalizations, days off school, days off work declared by households living in retrofitted houses	cost of illness (COI) quality-adjusted life year (QALY) value of a statistical life (VSL) A cost-benefit analysis of a randomized trial on retrofitting low-income communities in New Zealand with insulation is reported in Chapman et al. (2009)	88 billion EUR annual gross benefits at EU level from the deep energy-efficient renovation of the EU building stock: i.e. more health benefits than savings from lower energy bills, which are estimated as 75 billion EUR per year (Joyce et al. 2013). Other studies report that, for the private sector, such benefit may amount to the same order of magnitude as the energy-related benefits (Jakob 2006).
(Johnson Controls 2011; Lovins 2005), (Ürge-Vorsatz et al. 2014).	Productivity of workers/employees		Lovins (2005) argues that in efficient buildings "labour productivity typically rises by about 6–16%. Since office workers in industrialized countries cost ~100x more than office energy; a 1% increase in labour productivity has the same bottom-line effect as eliminating the energy bill".

Well-being measurement, according to (Ürge-Vorsatz et al. 2014), should include indicators dealing with quality-of-life and material living conditions, such as health status, life satisfaction, social connection, income, and wealth, etc. Here only health status is considered, to avoid co-benefits double counting.

3.3.3   Smart community co-benefits

Fuel poverty

Reference(s)	Indicators	Techniques	Figures
(Ürge-Vorsatz et al. 2010). Bone et al. (2010) Chapman et al. (2009) Williams et al. (2012),	Number of excess winter/summer deaths attributable to cold housing Number of households spending more than 10% of their income on energy bills	According to US EPA , as cited in Williams et al. (2012), the economic valuation of mortality impacts should include: • the value of reduced lifespan due to	In Hungary, more than 1,000 fuel-poverty-related excess winter deaths per year have been recently reported, affecting mostly seniors over 60 years old (Ürge-Vorsatz et al. 2010). Bone et al. (2010) report that a radicalization of

		premature mortality; • medical expenditures (e.g., for hospitalizations, medicines); the value associated with pain and suffering.	summer climate conditions is expected in the next years in UK, where, during the 2003 summer, characterized by intense heatwaves, over 2,000 extra deaths occurred.
	.		

To avoid double counting between the previous analyzed co-benefit "health and well-being" and "fuel poverty", the latter is here intended as related to extreme events only that lead to death and are related to the inability to ensure adequate indoor thermal conditions.

Users' awareness of energy-related issues

Reference(s)	Indicators	Techniques	Figures
Di Nucci and Spitzbart (2010) (Votta, 2012). Lewis et al. (2013)	Number of trained end users and hours of training	HC approach can provide a monetary estimation of knowledge gained through training or courses participation	-
(EEA 2013) Hori et al. (2013) Khandker et al. (2010) (Gill et al., 2010).	Energy behavior's changes (based on feedbacks)	Market or shadow price To measure the energy behavior's changes Hori et al. (2013) propose the following variables: (i) Energy saving behavior, (ii) global warming consciousness, (iii) environmental behavior and (iv) social interaction. Moreover, methods of impact evaluation of feedbacks on energy behaviors are in Khandker et al. (2010)	(Gill et al., 2010) reports that energy-efficiency behaviors account for 51%, 37%, and 11% of the variance in heat, electricity, and water consumption, respectively, among similar dwellings. The European Environment Agency (EEA, 2013) reports successful experiences in changing consumer behavior (up to 20% energy savings) through direct and indirect feedback,

Assessment of training effectiveness can be done by applying several models, as the Kirkpatrick's four-level evaluation model (reaction, learning, behavior, and results), and, consequently, it is possible to measure the return on investment (Roi) in human-resources development (Votta 2012). As argued by Lewis et al. (2013), training activities are often cost-effective.

Neighborhood identity

Reference(s)	Indicators	Techniques	Figures
Lee 2008 Di Nucci and Spitzbart 2010 EU 2013 OECD 2011	Social support, in terms of frequency of contacts and perception of possibility to count on someone else (Di Nucci and Spitzbart 2010) Population living in areas with integrated urban-development strategies (EU 2013)	CV: WTP for better social support CE technique can help to identify positive changes to neighborhood's key attributes defining its identity	-

Lee (2008) defined a conceptual model to investigate neighborhood quality of life (QOL) in Taipei, including identity and related variables, and OECD (2001) recalls how "investment in individual and group identity can lead to the creation of dense social networks and ultimately better economic and social outcomes".

3.3.3.1 Smart governance co-benefits

Decision-making processes

Reference(s)	Indicators	Techniques	Figures
(Borgatti and Candace 1998) (van Beurden 2011)	Number of people with increased professional capacity Acceptance of process and outputs	HC approach can provide a monetary estimation of increased professional capacity	-

The SSEDP environment, as a temporary organization and new system of relationships, forces actors to step away from their usual ways of doing, the so-called comfort zone (van Beurden 2011). This results in enhancement of motivation, knowledge, and skills, according to Borgatti and Candace (1998), as involved parties develop their needs, values, and expectations. This activates social-learning processes among participants, increases human capital, and creates new networks of social capital that are able to promote local contacts.

Territorial attractiveness

Reference(s)	Indicators	Techniques	Figures
(Campbel, 2012) (EU 2013) (Di Nucci and Spitzbart 2010)	Number of learning trips to demonstration sites Number of people involved.	Market or shadow prices Travel costs method	Campbell (2012) quantifies per each delegation seven-person team staying for four nights, with an average local expenditure of US$ 800 per capita.

EU (2013) suggests to consider as an indicator the increase in expected numbers of visits to supported sites and attractions, and this could be explored with the travel cost method. Additionally, Di Nucci and Spitzbart (2010) identify assessment of the increased visibility of the case-study area as an appropriate indicator for CONCERTO projects.

Institutional relationship and networks

Reference(s)	Indicators	Techniques	Figures
(Franceschetti et al. 2015) (Borgatti and Candace 1998) (A. Krishna and Shrader 2000) (OECD 2001)	Social capital in and between cities (trust, reciprocity, cooperation). Number affiliations in national, international networks or groups. Reputational power of the leader.	Investigating the influence of social capital through a social-network analysis (SNA) of the WTP for new energy-efficient technology.	-

Through the involvement in projects, institutions develop social capital that means networks, values, norms, and viewpoints. Such elements facilitate the cooperation between the involved institutions in exchanging resources, reaching project's results, and participating in new calls for projects funding, and so becoming more competitive (Franceschetti et al. 2015). For further resources, see Borgatti (1998), Franceschetti et al. (2015), Krishna and Shrader (2000), and OECD (2001). To our knowledge, a WTP study on this topic has never been published. However, Jones et al. (2009) carried out an evaluation of the interaction of social capital and WTP in the environmental field, which could be applied in the networking field. EU (2013) suggests considering as an indicator the number of research institutions and enterprises involved, or the number of enterprises cooperating, with research institutions.

3.3.4   Smart economy co-benefits

Tax revenues

Reference(s)	Indicators	Techniques	Figures
(Joyce et al. 2013) (Immendoerfer et al. 2014)	Local income tax revenues Labor income tax revenues	Direct monetary value	An extensive and deep renovation of the European building stock is estimated to have a positive impact on EU GDP of € 291 billion, generating therefore additional public revenues from corporate income tax or labor income tax and VAT (Joyce et al. 2013).

At the local level, the change in tax revenues is expected to be positive, because "Thinking the actual installation and maintenance of renewables, new buildings and retrofitting measures, the required work is typically undertaken by local professionals" (Immendoerfer et al. 2014).

Loan conditions

Reference(s)	Indicators	Techniques	Figures
(Hoffman and Henn 2008) (Di Nucci and Spitzbart 2010) (EU 2013) (Tirado Herrero et al. 2011)	Financing formulas and private investment (Payback period length)	Direct monetary value	-
(Immendoerfer et al. 2014)	Additional funds	Direct monetary value	-

In the US, some banks and other lenders recently started to offer energy-efficiency or green loans with special financing conditions (Hoffman and Henn 2008). Di Nucci and Spitzbart (2010) identify the payback-period length as an appropriate indicator for the assessment of CONCERTO projects. Moreover, private investment matching public support to enterprises (grants) and in innovation or R&D projects are indicators suggested by EU (2013). Tirado Herrero et al. (2011) argue that even if large-scale renovation programs are costly, especially on the upfront- cost side, some interesting financing formulas are suitable, e.g., pay-as-you-save, where the state provides interest-free loans. Immendoerfer et al. (2014) point out that although "CONCERTO funding (was) very small in comparison to total capital cost (it) was enough to stimulate other investment". Involved

municipalities "mobilised their own resources to subsidise projects further or drew on regional or national funding pots. These often came from urban renewal schemes or environmental funds", considering additional funding sources and revenues from feed-in tariffs "the picture would look very different for many projects" (Immendoerfer et al. 2014)

Labor market

Reference(s)	Indicators	Techniques	Figures
(Janssen and Staniaszek 2012) (Joyce et al. 2013) (Di Nucci and Spitzbart 2010)	Number and value of full-time employment positions created (FTE)	Direct monetary value	19 new direct local and non-transferable jobs in the construction sector for each € 1 million invested in energy-efficiency refurbishment of EU building stock (Janssen and Staniaszek 2012) from 760,000 to 1,48 million job opportunities, equal to a benefit to EU GDP of €153–291 bn depending on the level of investments (Joyce et al. 2013).

A broad global overview on the possible impact of the various low-carbon economy sectors on the creation of new green jobs, with adequate working conditions and wages, is widely discussed in UNEP/ILO/IOE/ITUC (2008).

Energy supply chain

Reference(s)	Indicators	Techniques	Figures
(IEA 2014b) (Di Nucci and Spitzbart 2010)	Avoided cost of by-products disposal (e.g., urban waste, sewage, or animal slurries)	Direct monetary value	An overview of investment costs and benefits related to a very large-scale biomass plant in Denmark, able to cover the demand for district heating in 5,000 homes and power consumption of 12,000 homes, are reported in IEA (2014a). In this example, a socio-economic value of 1 bn DKK over 20 years is declared, including avoided CO_2 emissions and animal-slurries disposal.

Since the exploitation of local renewable-energy sources is usually mentioned as a main SSEDP goal, the revenues generated by selling clean energy, as well as feed-in tariffs and avoided fossil-fuel consumption, should not be considered—the same for avoided CO_2 emissions. An increase in local control of energy supply and in local energy production are defined in the indicators' list elaborated by Di Nucci and Spitzbart (2010) for CONCERTO projects' assessment.

3.3.4.1 Energy services

Reference(s)	Indicators	Techniques	Figures
(UNEP/ILO/IOE/ITUC 2008) (Di Nucci and Spitzbart 2010)	Number of ESCOs established ESCOs revenues	Direct monetary value	In the last decades, ESCOs have funded $20-billions-worth of projects worldwide, about $4-billion in the US, more than a quarter of which is intended to design, install, operate, and maintain energy-efficiency measures in buildings (UNEP/ILO/IOE/ITUC 2008).

The SSEDPs' neighborhood approach can offer up options for financing solutions other than direct investment (Immendoerfer et al. 2014). Larger scales may provide better conditions due to the dimension of the intervention itself and multiple implementable measures.

Technology development and deployment

Reference(s)	Indicators	Techniques	Figures
(EU 2013) (Damm and Monroy 2011) (Ahearne et al. 2013)	Incomes from additional sales of the involved firms after the adoption of new technologies	Direct monetary value	-

According to Damm and Monroy (2011), innovative joint activities might sustain product or process innovation, therefore generally increasing revenues. Ahearne et al. (2013) propose a Technology Performance Usage Model (TPUM), to identify usage levels that lead to optimal effects on sales performance. This work was applied to 131 firms of various sectors; when focusing on the co-benefit effects, this model could be replicated by surveying the effects on the local firms involved in the project. EU (2013) suggests considering as an indicator the number of enterprises supported to introduce new-to-the-market products.

Professional skills

Reference(s)	Indicators	Techniques	Figures
(EU 2013) (Di Nucci and Spitzbart 2010) (Nosvelli 2009) (Cam 2012) (Tirado Herrero et al. 2011)	Number of trained professionals and number of training hours	HC approach can provide a monetary estimation of knowledge gained through training or courses participation	Cam (2012) stress how crucial are capacity-building programs to ensure an adequate design and operation of active design solutions in buildings. According to Tirado Herrero et al. (2011), the crew composition for deep-energy retrofit works should be on average 30% architects/professionals, 47% skilled workers, and only 23% unskilled workers.

The cost of training activities/courses offered is considered by Di Nucci and Spitzbart (2010) for assessment CONCERTO projects, and the number of participants in joint education and training schemes is suggested by EU (2013). Different methods to estimate the monetary value of HC are described in Nosvelli (2009).

3.3.5   Smart-built environment co-benefits

Property values

Reference(s)	Indicators	Techniques	Figures
(De Ayala et al. 2016) (Bottero et al. 2014) (Bonifaci and Copiello 2015) (Johnson Controls 2011) (Eichholtz et al. 2010b) (Fuerst et al. 2015) (EU 2013) (Di Nucci and Spitzbart 2010)	Number of properties with improved and certified energy performances	Hedonic price method Direct market value	A recent review on US green-buildings-market analysis reports an increased resale value from 5.8 to 35% and increased rental rates from 2 to 17%, coupled with a higher occupancy rates from 2 to 18% (Johnson Controls 2011). Bonifaci and Copiello (2015), studying an Italian city residential market, found a market price premium of 21.9% between "A" upper class and "G" worst; (De Ayala et al. 2016) offer a wide literature review on similar studies.
(Won Kim et al. 2003) (Lazrak et al. 2014)	Value of neighboring houses close to the demonstration site (not directly interested by refurbishment measures) where renewable energy sources are adopted	Spatial hedonic price method	-

A positive relationship between market value and building energy-efficiency class is usually recognized, although such price premiums widely vary across countries and territorial contexts (Bonifaci and Copiello 2015; De Ayala et al. 2016; Popescu et al. 2012). To the best of our knowledge, there are no previous studies tackling the issue of the "spillover effect" of SSEDPs on neighboring properties, however some other works use spatial hedonic methods to estimate the value of spatial components, as, for example, Lazrak et al. (2014) concerning the presence of cultural heritage sites in urban areas. Di Nucci and Spitzbart (2010) define the increase in real-estate value as an appropriate outcome indicator for CONCERTO projects, while EU (2013) suggests considering the number of households with improved energy-consumption classification.

Building life cycle cost

Reference(s)	Indicators	Techniques	Figures
(Gu et al. 2007) (Chen et al. 2011) (Hoffman and Henn 2008)(Stigka et al. 2014) (Ürge-Vorsatz et al. 2014)	Life-cycle cost of a green building (except for energy expenditures)	Direct market value CV: WTP for reducing the need for intervention, spare parts, and replacement hassles	Hoffman and Henn (2008) report savings in construction costs per retail branch by building to LEED standards of around US$ 80,000

In addition to previously mentioned benefits in the health and well-being of occupants, introducing energy-efficient technologies reduces maintenance, repair, operation costs, and longer lifetimes of hard-to-reach fixtures reduces the need for spare parts and replacement hassles (Ürge-Vorsatz et al. 2014). On the other hand, Hoffman and Henn (2008) point out that, despite the measurable benefits, individuals perception of green buildings is affected by cognitive biases that negatively impact their awareness of environmental impacts. Nevertheless, to our knowledge, a WTP study in this topic has never been published, while there are some studies investigating the social acceptance of renewable energy sources (see Stigka et al. 2014).

Energy infrastructure resilience

Reference(s)	Indicators	Techniques	Figures
(Evans and Fox-Penner 2014) (Manfren et al. 2011) (Schweitzer and Tonn 2002) (IEA 2014a)	Avoided cost of blackout and interruption Costs physical intervention of maintenance workers.	Direct market value	Schweitzer and Tonn (2002) estimate an NPV of US$ 33 to 80 related to transmission and distribution-loss reduction in providing less energy to retrofitted houses and a monetary benefit having NPV from $77 to 394, avoiding emergency calls in thermal services.

A wide selection of models for the planning and design of innovative urban-energy systems is reported by Manfren et al. (2011), and resilience often appears a key concept, as also stated by the IEA (2014a). EU (2013) suggests considering as an indicator the number of additional energy users connected to improved energy systems (i.e. smart grids).

3.4 Main findings and discussion

Following Table 2 summarizes the result of previous Section 3.3.

Smart City component	Co-benefit	Techniques for monetization						Human capital
		Existing markets		Revealed preferences		Stated preferences		
		Direct market value or shadow prices	Cost of illness	Hedonic prices	Travel costs	Contingent valuation	Choice experiment	
Smart natural environment	Air quality		T	V		V	T	
	Environmental resources management	V		T		S	S	
Smart services	Health and well-being		V			T	S	
Smart community	Fuel poverty		T					
	User awareness on energy-related issues	T				S	S	S
	Neighborhood identity					S	S	
Smart governance	Decision-making processes							S
	Territorial attractiveness	T			V			
	Institutional relationships and networks					S	S	
Smart economy	Tax revenues	T						
	Loan conditions	S						
	Labor market	V						
	Energy supply-chain	S						
	Energy services	S						
	Technology development and deployment	S						
	Professional skills							S
Smart build environment	Property value	V		V				
	Building life-cycle cost	T				S	S	
	Energy infrastructures resilience	S						

V = Estimated values reported by reference literature
T = Techniques or approaches assumed by reference literature
S = Techniques or approaches suggested by the authors by analogy to reference literature

Table 2: Techniques for co-benefits monetization

For six SSEDPs' co-benefit (improved local air quality, better environmental resources management, health and well-being increased, territorial attractiveness increased, stimulation of local labor market, and increased assets value), at least one value (V) has been found, while for four (tackling fuel poverty, increase in users' awareness on energy-

related issues, positive changes to local taxes revenue, and reduction in buildings' life-cycle costs) only related monetization techniques (T) are known. For the remaining nine co-benefits (enhancement of neighborhood identity, innovation in processes and decision making, institutional relationship and networks created, loan conditions, local energy-supply-chain development, energy-services establishment, innovation in technology development and adoption, professional skills development, and resilience of energy infrastructures) direct studies have been not found during this first review, and therefore techniques have been suggested by analogy (S).

These findings can be considered the starting point for each project assessor in charge, to draft a comprehensive CBA of an SSEDPs, not only considering the "hard measures" implemented, but assuming the whole perspective of a knowledge-creation environment. This is a holistic approach where, new attitudes, knowledge, and social networks, mainly related to the "soft measures", are likewise as important as the physical interventions.

The investigation shows how not adequately explored are the topics related to social capital and human capital, although positive outcomes in these fields are often made evident by projects. Although tools for their analysis are available, monetization techniques need to be further investigated. Conversely, for the majority of other co-benefits, it is more of a fine-tuning effort, to contextualize well-known economic assessment methodologies. Therefore, consideration of the key urban co-benefits within a CBA of an SSEDP is feasible and needed. It is obviously crucial, even before defining the assessment methodology, to establish appropriate indicators, capable of grasping the magnitude of each co-benefit at the urban level, and possibly its flow over time. Assessment experiences of previous projects may be a coherent reference. It is worth mentioning, that there are criticisms of the CBA, where not only monetary outcomes are considered. On the other hand, Ürge-Vorsatz et al. (2014) argue that "for the assessment of the co-impacts (…), social cost-benefit analysis is the preferred appraisal tool because it measures costs and benefits as variations in human well-being". Thus, monetizing co-benefits could be a promising strategy for evaluating the total impact of comparable projects, such as SSEDPs, and effectively supporting their diffusion. Because such a methodology is extremely useful for understanding the monetary impacts of projects, at least four relevant issues in co-benefits appraisal should be considered. The first concerns the quality and reliability of the input data: are these both enough precise and trustworthy? Co-benefits accounting encounters various challenges related to possible interactions and synergies, double counting, context dependency, and distributional issues. The suggestion is, therefore, to keep the list concise. The second considers the probability of occurrence: is the co-benefit absolutely certain or would it only likely be

present? A prudential approach could be to distinguish between "real" co-benefits and those defining as co-opportunities (see Chapter 3, and, in particular, Section 3.2 of this thesis). The third aspect deals with the effort of scientific investigation of co-benefits, compared with their relative value: is it worth it? Generally speaking, the adoption of other indicators or techniques will probably lead to different estimates for the same co-benefit, and, for the less relevant, the benefit-transfer method could be the most cost-effective solution. Finally, the heterogeneity of impacts is also a matter of concern. They can arise on the individual to sectoral level and range from local to international dimensions (IEA, 2014a): how to satisfy the need to consider, according to Ürge-Vorsatz et al. (2014), "the relevant groups of stakeholders at an appropriate scale"? As the local authority should ensure within the decision-making process adequate welfare balance to the whole community, and not only to the project's consortium or actively involved citizens, the urban dimension seems to be the adequate reference scale for SSEDPs co-benefit assessment.

Chapter 4 - A hedonic price model of energy performance of buildings

Sustainable buildings with outstanding energy performance are attracting the interest of academics from various fields including engineers, architects, urban planners, sociologist, and economists. As a result, studies on this topic explore various directions, mainly related to the implementation of new materials and energy-efficient technologies, innovative design approaches, understanding of users' behaviors and health conditions, and maintenance costs and benefits (Acre and Wyckmans 2015; Aelenei et al. 2013; Preval et al. 2010; Stuart 2012; Thatcher and Milner 2012). Moreover, real-estate operators and specialized research departments are interested in deepening the knowledge about energy and overall sustainability performance of specific categories of buildings and their market value (Antoniucci et al., 2015b; Bonifaci and Copiello, 2015; De Ayala et al., 2016), by implementing various research methodologies, e.g., the hedonic price method.

The aim of this chapter is, therefore, to shed light on the existence and relevance of the marginal contribution of high-energy classes in determining the asking price for residential buildings in the city of Bolzano, the main city of South Tyrol. A spatial hedonic price model is proposed on the basis of 1,130 sales advertisements collected in the first half of 2016, within the boundaries of the so-called "SINFONIA project district" (for additional info see Chapter 1 and following Section 4.4). The database is analyzed, and the hedonic price-function model is implemented by using ESRI ArcMap 10.3, a leading commercial Geographical Information System (GIS) software, and GeoDa 1.8.14, a free GIS developed by Anselin. The proposed spatially-explicit model combines traditional hedonic regression with spatial information, enabling more detailed and reliable results.

This chapter is organized as follows: Section 1 recalls the rationale of the assessment of the energy performance of buildings. In Section 2, the hedonic price method and its spatial specifications are illustrated. In Section 3, a brief exposition of similar studies applying this technique is illustrated. Section 4 provides an overview on the dataset and variables, while Section 5 treats the results of spatial analysis. The modeling strategy is explained in Section 6, and main results reported and discussed in Section 7.

4.1 Energy performance certification of buildings

The Energy Performance of Buildings Directive (EPBD) (EU 2002) is the main pillar of the EU policy related to the energy performance of buildings. Through the implementation of the directive, the EU aims to reduce its final energy demand by 6.5% by 2020, corresponding to the equivalent of nearly one-hundred-million tons of oil (Mtoe). One of the key points of EPBD is the introduction of the building Energy Performance Certificate (EPC). The EPC, drafted and signed by a professional technician, must provide an energy-efficiency rating and must be available to the owner (or to the prospective owner/tenant) when the building is constructed, sold, or rented out. The EPC is valid for ten years, and the rating for the energy performance, similar to that already attached to several domestic appliances or car tires, ranges from "A" (best class) to "G" (worst, i.e. very inefficient). The EPBD recast in 2010 (EU 2010) helped to clarify some application questions and strengthened the leading role of the public sector in promoting energy efficiency in the construction sector (European Commission 2008). Another relevant topic is the obligation introduced for member states to ensure that, by 2020, all newly constructed buildings are nearly-zero-energy buildings (i.e. have very-high energy performance). Moreover, it anticipates the requirement explicitly about the information provided by the Energy Performance Certificate (EPC), from the moment of signing the contract (regardless if for sale or rental) to the moment of advertising the property.

In Italy, the progenitor of the building-energy-efficiency legislation is law 10, entered into force in 1991, introducing the requirement for technical calculation and caps concerning the amount of energy needed annually by the building. The Legislative Decree 192 of 2005, transposing the EPBD to the national framework, amended essentially the application of the law 10/91. The recast previously-mentioned EPBD has been finally implemented by the law 90 in 2013, now in force in Italy.

It is worth nothing that the implementation level of the EPBD differs across the member states. Nevertheless, the main trend toward having high-energy-performance buildings is clearly defined, although the content of EPCs specified in the various national laws is not easily comparable, and the calculation procedures are not homogenous. It should also be said, that, in Italy since the Legislative Decree 192 of 2005, the regions and the autonomous province of Trento and Bolzano (i.e. South Tyrol) gained full autonomy in the energy management of the territory, and some of them issued rules differing from those applied at the national level.

In particular, in South Tyrol, the EPBD recast is implemented by the deliberation 362 of the Provincial Government on March 4, 2013, and the building EPC is issued by the public agency "CasaClima". Nestled in the mountains of the Alps, South Tyrol is the northernmost Italian province, with a severe winter climate. This is also the richest province, with a high quality of life. Generally speaking, South Tyrol demonstrates a well-developed environmental consciousness, and the history of the public agency "CasaClima", with roots in the early 1990s, is a success story. The standard defined by the "CasaClima" agency (see Fig. 5) is stricter than the national, and the local certification system is a benchmark at the national level for other regions developing their own regulations on this topic. The "CasaClima" EPC, which differs from the national EPC as defined on a whole building, is also valid when selling or renting each one of its apartment. Alternatively, for the sale or rental of a single apartment in a building without the "CasaClima" EPC, an EPC complying with the national requirements and drafted by a qualified technician can be drawn up.

Classe Casa Clima	Efficienza Energetica Involucro (EIN) [kWh/m²a]	Fabbisogno Energia Primaria Equiv. Senza Raffrescamento (EPSR$_{RES}$) [kg CO$_{2\,eqv}$/m²a]	Fabbisogno Energia Primaria Equiv. Raffrescamento (EPR$_{RES}$)** [kg CO$_{2\,eqv}$/m²a]	Efficienza Energetica Complessiva (EEC$_{RES}$) (= EPSR$_{RES}$+ EPR$_{RES}$) [kg CO$_{2\,eqv}$/m²a]
Gold*	≤10	≤10	≤5	≤15
A*	≤30	≤20	≤10	≤30
B	≤50	≤35	≤15	≤50
C	≤70	≤50	≤20	≤70
D	≤90	≤65	≤25	≤90
E	≤120	≤90	≤30	≤120
F	≤160	≤120	≤40	≤160
G	>160	>120	>40	>160

Figure 5: Energy Performance Classes defined by CasaClima Agency – City of Bolzano

In this context, several local construction companies offering high-energy performance wooden houses are being established. They also promote the adoption of natural materials in the retrofitting of existing buildings for insulation or timber for the extension. The feeling is that energy efficiency in buildings matters for South Tyroleans, and that could be a characteristic appreciated by the real-estate market, as the literature in this field suggests.

Indeed, this issue has been approached by some studies from the perspective of sales-price premiums for certified green or high-efficiency buildings, compared with the average value of existing building stock (Eichholtz et al. 2010; Stuart 2012). However, the real-estate value, according to Forte (1973) and Orefice (1984), is not only related to categories of factors concerning the building itself, its systems, and its attitude to generate

income. Also relevant are the context of where the asset is located and the legal framework to which it is subjected. As De Ayala et al. (2016) recently observed in Spain, homes located in different cities in the same country are differently valued, *ceteris paribus*. Thus, one cannot assume that observations conducted in a nearby region or city, also considering the same variable and in a short space of time, will certainly lead to similar results. To the best of our knowledge, there are no previous studies tackling this issue conducted on the in South Tyrol's real-estate market.

4.2 Hedonic price and spatial techniques

<u>The hedonic price model</u>

The value of a real-estate propriety, defined as the most probable selling price on the market, is estimable by applying various appraisal methods. A first distinction should be done between indirect (or analytic) and direct (or synthetic) methods. Indirect methods are adopted when the market for a certain typology of propriety is poor or even absent, while the latter can be applied in an existing and active market, with real transactions. The analysis is usually done with a comparison between the object to be evaluated and the market prices of similar proprieties. Such direct appraisal methods are in turn classified as monoparametric or multiparametric. The first are based on the comparison of a single paramount characteristic, mainly the dwelling's surface, and provide reliable results only if the considered goods are suitably homogeneous. The latter investigate multiple variables affecting the final real-estate value and are useful in contexts where the goods' heterogeneity is predominant. One of the fundamental multiparametric technique in the Italian real-estate appraisal school is the so-called "punti di merito" approach, developed by Forte in the 1970s (Forte and De Rossi 1973). Forte's approach is founded on the assumption that, if a certain property, similar to that we want to estimate, has the higher price on the market, it is, therefore, the one with the highest score (i.e. 100 points) based on four broad groups of characteristics (extrinsic location characteristics, intrinsic location ones, technological, and productive). The value of the object of estimation will be calculated as a weighted sum of its performances in the four categories and will be, obviously, less than or equal to the reference case. The main critiques of this approach are the difficulty of obtaining the higher transaction on the market and the weight's definition. Additionally, some intrinsic or extrinsic characteristics may be affected by complementarity and reciprocity, because they are not practically distinguishable from the property as a whole.

To overcome these weaknesses, other methods, based on multiple regressions models, were developed with the aim of identifying the marginal contribution of a certain variable in the price function. The hedonic price model (HPM) is an econometric technique based on the rationale that the price of a certain good is a function that combines proper characteristics and external factors (Rosen 1974). HPM originated from Lancaster´s attribute theory, for which a value of a good is given by the sum of the values of its relevant attributes (Lancaster 1966). By analyzing a sample of the real transaction in the housing market, it is possible to extrapolate the implicit price of a single characteristic and, consequently, understand how the price is expected to change with respect to a reference case. The main arguments underpinning the reliability of the results are basically given by the quality of the sample, the right variables' definitions, and the appropriate algebraic function. In short, HPM enables estimating how different attributes are capitalized in housing prices (Dastrup et al. 2012) or, in other words, the difference in the whole price is determined by the variation of each single selected variable.

The form of the HPM function is not known *a priori*, the economic theory places few restrictions on it, and the most recurrent in literature are the linear function, the log-log, the semi-log, and the Box-Cox (Bravi 2000; Stellin and Rosato 1998; Won Kim et al. 2003). The standard HPM function is given by:

$$P = \beta Z + \varepsilon$$

Equation 2 – HP function

where *P* is the *n x 1* vector of dependent variables (i.e. property or surface unit prices and transaction or asking prices), *Z* is the *n x j* matrix of characteristics (i.e. explanatory variables), *β* is the *j x 1* vector of coefficients associated with explanatory variables, *ε* is assumed to be a *n x 1* vector of independent, and identically distributed random-error terms. The model is typically estimated using the ordinary least-squares (OLS) method, and *n* is the number of observations recorded (i.e. transactions or advertisements).

Among others, the HPM has been recently adopted to investigate how house prices may change due to the achievement of better energy performance, or by adopting renewable-energy systems, or even based on air-pollutant concentrations or proximity to green spaces. Bonifaci and Copiello (2015) analyze the price premium of energy efficiency in the real-estate market in Padova, a northern Italian city, while Bottero et al. (2014) tested this in Torino. De Ayala et al. (2016) conducted a similar investigation on the higher energy-efficiency classes (A, B, C, and D) in some Spanish cities, and, earlier, Dastrup et al. (2012) probed the economic benefit of having solar panels on the rooftop in San Diego County, California (U.S.). In the HPM, the function represents the real-estate market of a certain well-defined territorial context (e.g., an urban area or a neighborhood),

and the partial derivative of each one of the various explanatory variables represent the marginal implicit price of each characteristic (Bravi 2000).

Spatial techniques in hedonic price modeling

Tobler's First Law of Geography states that "all places are related but nearby places are more related than distant places" (Tobler 1970), and, because the location is axiomatic in determining the real-estate value (Krause and Bitter 2012), several attempts have been made to incorporate this into house-price spatial modeling. This is also relevant keeping in mind that a neglected consideration of spatial relationships, in the presence of spatial dependence, will lead to biased results (Anselin 1988). As recalled by Won Kim et al. (2003), the first empirical works in this field are those by Dubin and Can in the early 1990s. The spatial approach couples the information of the mere existence, or lack, of external factors with their proximity to the investigated object (Anselin 1988), consequently it makes possible defining spatial relationships between external variables and the price function. As a result, a spatial-hedonic-price (SHP) method may be implemented. In respect to this, Won Kim et al. (2003) offer an interesting application investigating the negative correlation between air pollution (i.e. SO_2 and NO_x levels) and property value in the Seoul metropolitan area. More recently, Herath et al. (2015) provide evidence of the negative relationship between the apartment price and the variable "distance from the greenbelt" (i.e. a broad system of green public spaces and woods). Both these studies, having found the presence of spatial autocorrelation in the basic OLS model, tested the Spatial Lag Model (SLM) and the Spatial Error Model (SEM), which are often adopted in spatial-dependency investigation applied to real-estate markets (Krause and Bitter 2012). The SLM assumes the presence of an indirect effect given by the prices of nearby property on the price of each propriety (i.e. the spillover effect) so:

$$P = \rho W P + \beta Z + \varepsilon$$

Equation 3 – SLM function

where ρ is a spatial dependence parameter, W is a n x n spatial weight matrix (n is the number of observations considered in neighborhoods relationships), and other symbols are as defined in Equation 2 – HP function. The SLM cannot be solved by OLS estimators since that would be inconsistent and biased: the maximum-likelihood estimation (ML) needs, therefore, to be employed (Anselin 1988).

The W is a positive matrix with non-zero elements in those row–column combinations corresponding to observational units that are assumed to interact. Typically, the definition of neighbors used in the W is based on a notion of distance decay or contiguity (having common borders). By convention, the diagonal elements of W are set to zero and the row

elements are standardized such that they sum to one. The type and extent of the *W* bandwidth are defined in various ways (e.g., kernel type, distance, the number of neighbors, etc.).

Conversely, the SEM neglects such indirect effects, postulating the presence of one or more hidden and spatially related variables in the error term of the hedonic price equation, as follows:

$$\begin{cases} P = \beta Z + \eta \\ \eta = \lambda W \eta + \varepsilon \end{cases}$$

Equation 4 – SEM function

where *λ* is the coefficient expressing the strength of spatial autocorrelation within residuals and other symbols are as defined in Equation 2 – HP function.

When the global Moran test suggests the presence of spatial autocorrelation (this should be tested with different specification of *W)* to determine which alternative spatial specification should be used, Anselin (2005) offers a decision-rule flowchart, based on the results of multiple Lagrange Multiplier test statistics (Fig. 5).
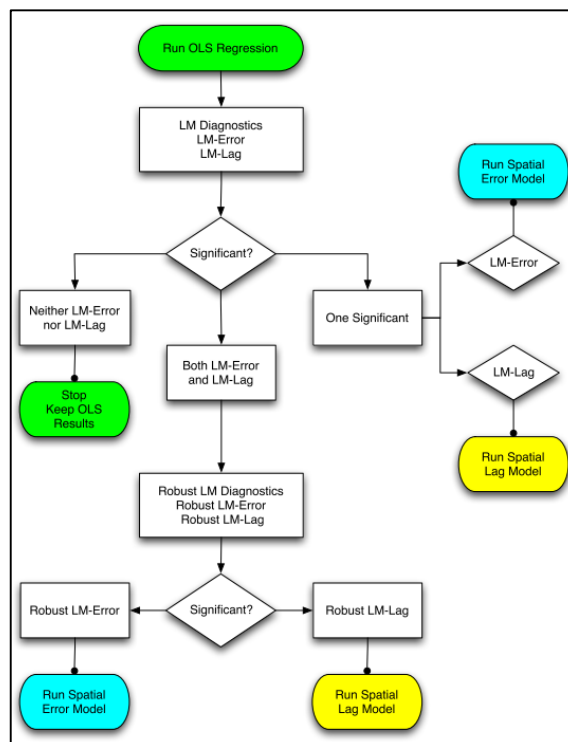

Figure 6: Spatial modeling decision rules. Source: Anselin (2005), pg.199.

The decision is taken on the basis of the Lagrange Multiplier (LM) tests' significance (Anselin 2005; Herath et al. 2015):

- If LM-Lag test → H_0: $\rho = 0$, then the SER should be tested;

- If LM-Error test → H_0: $\lambda = 0$, then the SLM should be tested;

- If neither LM-Lag test or LM-Error test are significant the OLS is the appropriate model;

- If both LM tests are significant, then the analysis path is decided looking at the higher level of significance of Robust LM (RLM) tests result.

Other studies, having found both LM tests significant, suggest to shift to estimate also the spatial Durbin Model (SDM) that addresses spatial dependence across observations in both the dependent and independent variables (Herath et al. 2015; Lazrak et al., 2014), but this is beyond the range of investigation of this research.

An alternative statistical technique that allows variation of model coefficients over space is the Spatially Weighted Regression (SWR) (Fotheringham et al. 2002). Thus, the SWR provides a unique equation for every observation, considering the dependent and explanatory variables of other observation within the defined bandwidth of each observation. According to (Wheeler and Tiefelsdorf 2005), the main criticism of GWR is the lack of diagnostic tools (especially because local multicollinearities and the influence of a local outlier may be strong), and the fact that "GWR ignores that the local models must relate to a global reference model in order to express the local parameters as variation around their global counterparts" (Wheeler and Tiefelsdorf 2005). Therefore, GWR should be used as more of an exploratory tool.

4.3 Survey of similar studies

Table 3 compares the main points of the above-mentioned studies related to sustainable buildings, environmental features and/or spatial hedonic modeling. These studies confirm how, in different magnitudes, energy efficiency and green attributes of buildings, as well as positive environmental conditions, are appreciated by owners, and therefore translated into the real-estate prices (or asking prices).

Reference	Country	Topic	Spatial specifications	Model	Main findings
(Bonifaci and Copiello 2015)	Italy	Energy performances	Districts	OLS	EPC price-premiums comparing G to: A/B= 21% ; C/D= 17%; E= 9%
(De Ayala et al. 2016)	Spain	Energy performances	Cities	OLS	EPC price-premium comparing G to: ABC= 10%; ABCD= 5%
(Dastrup et al. 2012)	California (U.S)	Renewable energy	Districts	OLS	Solar panels price-premium= 4%
(Herath et al. 2015)	Austria	Environmental characteristic	Districts Distances	OLS SEM SDM	OLS model overestimates positive effects of proximity to green areas

(Won Kim et al. 2003)	Korea	Environment	Districts Distances	OLS SLM	OLS model overestimates positive effects of reducing air pollutant concentration
(Lazrak et al. 2014)	Netherlands	Historic heritage	Distance to center	OLS SDM	OLS model underestimates the positive value of cultural heritage, neglecting the spillover effect.

Table 3: Summary of literature review

Besides different variables' consideration, these studies demonstrate how the use of asking, instead of transaction, prices in defining the HPM is accepted by the literature (Bonifaci and Copiello 2015; Bottero et al. 2014; Herath et al. 2015), and, sometimes, also owner self-assessed values are used (De Ayala et al. 2016; Won Kim et al. 2003).

Energy classes are each used as a dummy variable (Bonifaci and Copiello 2015) or grouped into broader groups (e.g., premium classes) (De Ayala et al. 2016). The heating/cooling type is also investigated (De Ayala et al. 2016; Won Kim et al. 2003), as the presence of renewable sources (Dastrup et al. 2012). Concerning spatial variables, the city districts are widely used (Bonifaci and Copiello 2015; Dastrup et al. 2012; Herath et al. 2015; Won Kim et al. 2003), in combination with distances or travel distances between relevant urban locations. Studies, where the spatial autocorrelation of data is found relevant, demonstrate how the OLS model provides biased results (Herath et al. 2015; Lazrak et al. 2014; Won Kim et al. 2003).

4.4 Data collection and variables

As said before, the function form of the HPM equation is not known but can be discovered by an empirical approach. Therefore, the accuracy in the dataset construction is crucial to obtain reliable results (Bravi 2000). The original dataset of this study encompasses 1,130 residential-apartment advertisements for sale properties in the city of Bolzano (northern Italy).

Bolzano, the administrative center of South Tyrol, has close to 106,000 inhabitants over an area of 53 km^2, with an average density of 2,033 Inh/km^2. Data collection lasted from May to July 2016 and was done through a specialized website. The accuracy and completeness of web-published advertisements widely vary even within the same website; the most difficult information to get is the address of the apartment, due to privacy issue and commercial reasons (see Table 4). This information was crucial for a better specification of a spatial HPM, and also to narrow down the investigation area to the so-called "SINFONIA district", which excludes the historical center of the city, the industrial district, and the neighborhood named "Ai Piani", located on the other side of the main railway station. The reason was two-fold: first to exclude areas where prices may be influenced by additional factors, given the specificity of the context, and, second, to take advantage of research results from the SINFONIA project, available only within the

specified area. Thus, the dataset is the result obtained after filtering more than one thousand available advertisements, with the collaboration of local real-estate agencies, responsible for managing it. By doing so, it was possible to clarify some questions, correct inconsistent information, and improve the overall quality of the sample. All properties were geolocated (i.e. matching the database with the street name) by using Google Maps and then exported as a KML file. Finally, by using the software ArcMap 10.3, the KML points were converted into shapefile features and then paired with advertisements. Tab. 4 recalls the dataset refinement steps.

Steps	Obs.	File
Original dataset	1,130	HP_BOLZANO_ADVS.xls
Geo-localized at street level	1,029	HP_POINTS_FROM_KLM.shp
Within administrative border of Bolzano	1,026	HP_POINTS_BOLZANO.shp
Within Sinfonia district border	800	HP_POINTS_SINFONIA.shp
Excluded surface outliers (< 250 mq)	798	HP_POINTS_THESIS.shp
Excluded "EPC under development"	650	HP_DATASET_ENERGY.shp

Table 4: Dataset creation process

Through these steps, it was possible to assign each advertisement to a specific city district (and street) in order to conduct the further spatial analysis. Moreover, a few apartments of more than 250 m^2 were discarded, because they were, in fact, entire buildings, instead of apartments. To reduce biases, the advertisement reporting "EPC under development" or similar statements (e.g., attributed the "G" class before technical assessment or left it blank) were also filtered and excluded.

The variables collected in the investigation phase are more than those considered in the final model specification because is obviously not possible to know in advance what are the most relevant. The following Table 5 and 6 summarizes the variables and related descriptive statistics later used for estimation (see Section 4.6). The district perimeters were specified according to information provided by the Observatory of Italian Tax Agency (OMI) that slightly differ from administrative districts of the municipality of Bolzano.

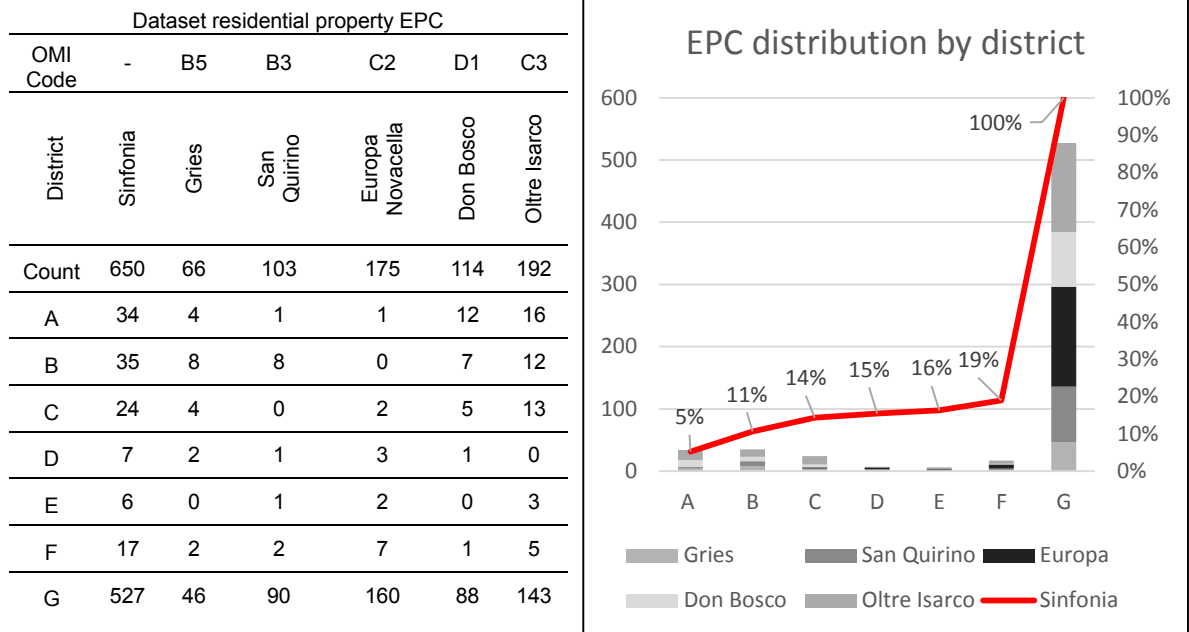| Dataset residential property EPC						
OMI Code	-	B5	B3	C2	D1	C3
District	Sinfonia	Gries	San Quirino	Europa Novacella	Don Bosco	Oltre Isarco
Count	650	66	103	175	114	192
A	34	4	1	1	12	16
B	35	8	8	0	7	12
C	24	4	0	2	5	13
D	7	2	1	3	1	0
E	6	0	1	2	0	3
F	17	2	2	7	1	5
G	527	46	90	160	88	143

Figure 4: EPC distribution by city districts

Looking at the energy performances reported by advertisements, as defined in the EPC, the dataset is dominated by the worst class "G", accounting for 80% of collected advertisements (527 on 650). Premium classes "A" and "B" cover respectively 5 and 6%, while intermediate "D" and "E" are almost neglected (see Fig. 7.). Particularly, properties labeled "high level" are offered within the Don Bosco and Oltre Isarco district. They never appear in Europa-Novacella, where almost all properties are rated "G".

The property value in the collected advertisements widely vary across districts and is substantially in line with values recorded by the Observatory of Italian Tax Agency (OMI), as reported in Table 4. Moreover, in general, property asking prices range from 100,000 to 1,100, 000 € (average price is 317,211€ and std. dev 149,114€)

Dataset residential property value (€ / square meter)

OMI Code	-	B5	B3	C2	D1	C3
District name	Sinfonia	Gries	San Quirino	Europa Novacella	Don Bosco	Oltre Isarco
Count	650	66	103	175	114	192
Min.	1,265	2,106	2,400	1,265	2,157	1,938
Max.	8,524	8,415	8,524	4,500	4,588	5,500
Mean	3,405	4,349	3,656	3,362	3,295	3,052
St.Dev.	733	1,033	911	466	499	505
OMI residential property value (€ / square meter), having good maintenance condition						
Min.		3,400	3,300	2,800	2,600	2,700
Max.		4,800	3,800	3,500	3,300	3,200
Mean		4,100	3,550	3,150	2,950	2,950
OMI residential property value (€ / square meter), having very good maintenance condition						
Min.		4,500	3,800	3,300	3,100	3,000
Max.		6,500	4,900	4,200	3,800	4,000
Mean		5,500	4,350	3,750	3,450	3,500
Mean of OMI residential property value (€ / square meter)						
		4,800	3,950	3,450	3,200	3,225

Table 2: Residential property value in Bolzano

Concerning apartment dimension, in the whole sample, we find a mean value slightly above 100 m^2, with the largest apartments in Gries and San Quirino (which are the older city districts) and the smallest in Don Bosco and Oltre Isarco. Thus, the mean values in the districts range from near 115 m^2 to 82 m^2 (see Table 5).

Dataset residential property surface (square meters)

OMI Code	-	B5	B3	C2	D1	C3
District name	Sinfonia	Gries	San Quirino	Europa Novacella	Don Bosco	Oltre Isarco
Min.	25	33	35	40	30	25
Max.	240	205	240	177	140	196
Mean	92.61	114.36	115.19	85.69	87.35	82.44
St.Dev.	33.81	42.36	40.50	28.19	24.17	26.49

Table 3: Residential property surface in Bolzano

4.5 Spatial analysis

The data set is first generally examined to determine how property prices are distributed in Bolzano (i.e. clustered or dispersed); then some tools performing local statistical tests are run (on the shape HP_DATASET_ENERGY.shp) to see where clusters exist.

4.5.1 Weighted Spatial Matrix generation

The definition of the spatial weights matrix (W) is the first step, before starting the tests for spatial autocorrelation and consequent modeling of the spatial relationship among properties prices. The W explicitly describes the neighborhood relationships, but it is not known *a priori* what spatial structure is the most appropriate to describe them. Thus, three spatial weights matrices are generated and tested. They are row-standardized and distance-based. The conceptualization of spatial relationships among features is defined following the inverse distance method (i.e. nearby neighboring features have a larger influence on the computations for a target feature than features that are further away). Three different thresholds are defined in searching for neighboring properties: 500 mt, 750 mt, and 1000 mt (see Table 6).

W Name	W_500	W_750	W_1000
Threshold Distance:	500mt	750mt	1000mt
Number of Features:	650	650	650
Percentage of Spatial Connectivity:	13.75	21.28	31.23
Average Number of Neighbors:	89.40	138.29	203.01
Minimum Number of Neighbors:	1	17	49
Maximum Number of Neighbors:	139	229	346

Table 4: Spatial Weights Matrices Summary

4.5.2 Getis-Ord General G statistic

The first tool applied is the Getis-Ord General G statistic to see if dwellings with a high or low asking price (ASKING_PRICE) or square meter asking price (SMAP) are clustered; in this case, the lowest research threshold (500 mt) still ensures that all features have at least one neighbor.

ASKING_PRICE	SQMPRICE

```
Observed General G: 0.026891
Expected General G: 0.033759
    Variance:    0.000002
    z-score:    -5.597273
    p-value:    0.000000
```

```
Observed General G: 0.029752
Expected General G: 0.033759
    Variance:    0.000000
    z-score:    -7.133826
    p-value:    0.000000
```
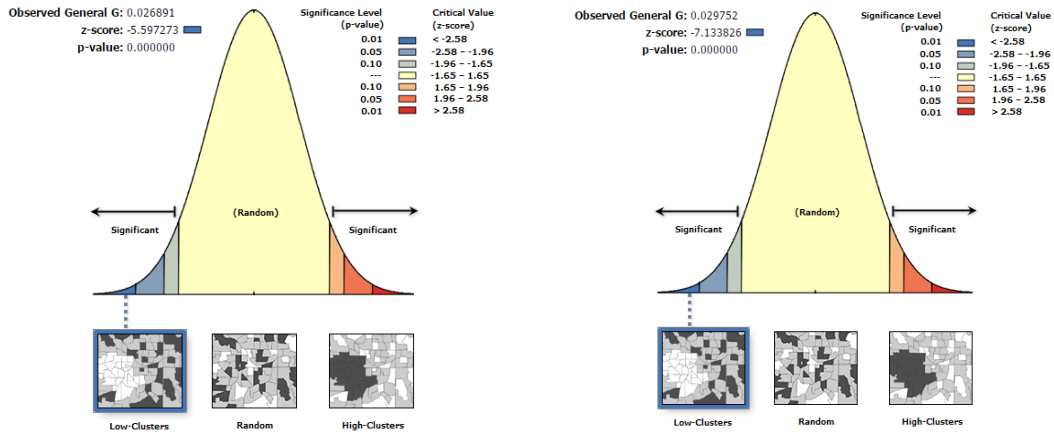

Figure 5: General G Summary

Because the p-value is statistically significant, the null hypothesis should be rejected. In particular, given the high negative z-score, there is a less than a 1% likelihood that the lowly-clustered pattern recognized could be the result of random chance. The distribution of lower values of the variables ASKING_PRICE and SMAP seems to be significantly more clustered than a random pattern (see. Fig. 8). This result is also confirmed when moving the distance threshold to 750 or 1,000 mt.

4.5.3   Spatial Autocorrelation—Global Moran's *I* statistic

Then, the Spatial Autocorrelation tool is applied to see if the general pattern of features is clustered or dispersed (as opposed to a clustering specifically related to high or low values). In this case, the spatial autocorrelation is measured based on feature locations and attribute values using the Global Moran's *I* statistic. In general, a Moran's-Index value near +1.0 indicates clustering, while an index value near -1.0 indicates dispersion.
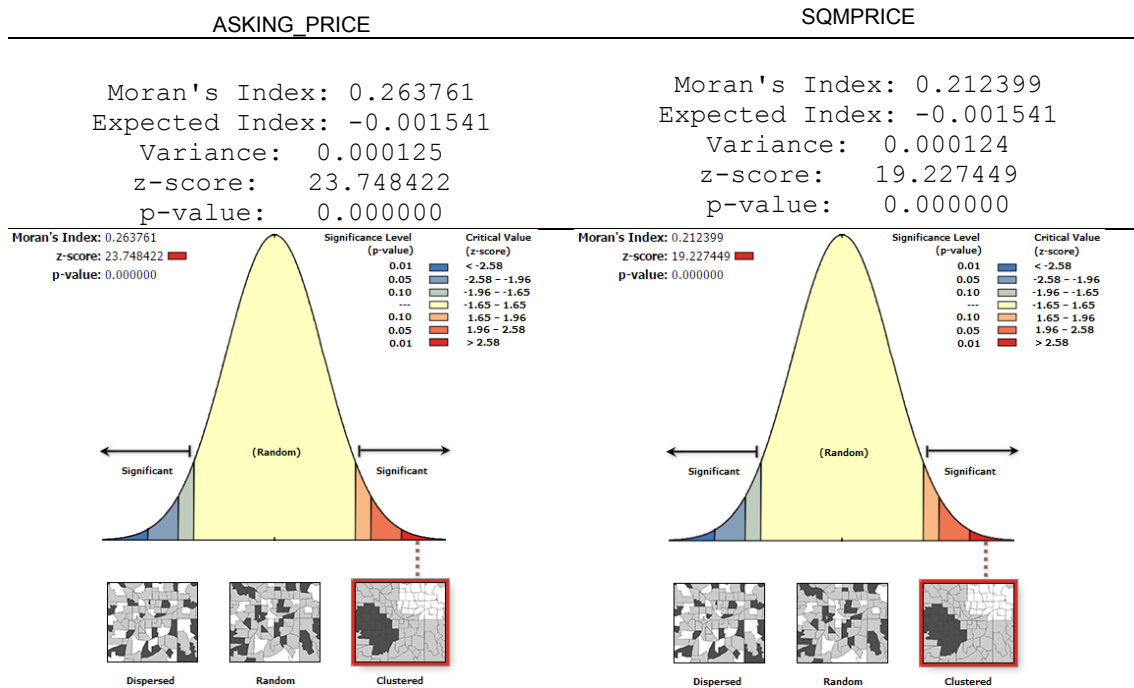
ASKING_PRICE	SQMPRICE

```
Moran's Index:  0.263761
Expected Index: -0.001541
   Variance:    0.000125
   z-score:     23.748422
   p-value:     0.000000
```

```
 Moran's Index:  0.212399
Expected Index: -0.001541
   Variance:    0.000124
   z-score:     19.227449
   p-value:     0.000000
```


Figure 6: Global Moran's *I* statistic

Here the Moran's expected index was slightly negative, versus a calculated close to 0.26 (ASKING_PRICE) or 0.21 (SQMPRICE) (see Fig. 9). Clustered patterns are therefore revealed at a significance level of p-value < 0.01. Thus, given the positive z-score, there is a less than 1% likelihood that this clustered pattern of high values could be the result of random chance (i.e. the null hypothesis of randomly distributed records in the study area is rejected). As before, the result is also confirmed when widening the distance threshold.

4.5.4   Cluster and Outlier Analysis

The Cluster and Outlier Analysis is a tool that, given a set of weighted features, identifies statistically significant hot spots, cold spots, and spatial outliers using the Anselin Local Moran's *I* statistic. The graphic output is a map representing different cluster and outlier types. Three different threshold distances were tested: (i) 500 mt and (ii) 750 mt. and 1,000 mt. Although specific coefficients (z score and p-value) slightly differ among the tests, the cluster analysis results mainly agree.

The label HH indicates that the relationship is high-high: a record with a PRICE/SMAP value significantly higher than its neighbors is surrounded by others also having high PRICE/SMAP values. This means that, although in general there are high values in that area, there are significantly higher values in that specific place, as it is found in Gries and San. Quirino, as illustrated in Fig. 10. The opposite is true for the low-low relationships. For the record that has a significant low-high relationship with its neighbors, its asking

price is low in general, and it is surrounded by others with significantly higher values. In the map concerning SQMPRICE, we notice a large cluster of low-low values (LL) in Aslago (the northern part of Oltre Isarco district), having nearby high-low values (HL). Low-high values (LH) clusters were found between S. Quirino and Gries.
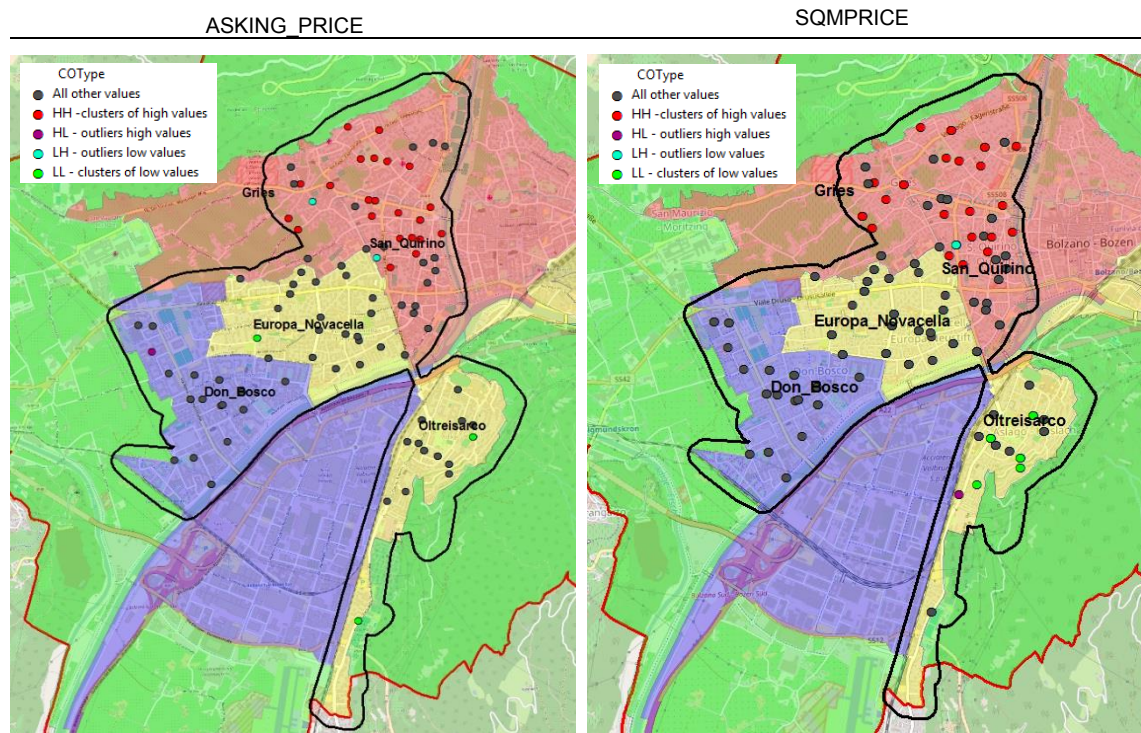
ASKING_PRICE   SQMPRICE

Figure 7: Cluster and Outlier Analysis

4.5.5 Hot-Spot Analysis (Getis-Ord G_i^*)

To discover where median SMAP values are clustered, a local version of the previous founded G score is calculated, by using the Hot-Spot Analysis (Getis-Ord G_i^*) tool. Given a set of weighted features, it identifies statistically significant hot spots and cold spots using the Getis-Ord G_i^* statistic. While the Spatial-Autocorrelation tool assesses the overall pattern and trend of the dataset and is therefore more effective having a spatial pattern consistent across the study area, the Hot-Spot Analysis assesses each record within the context of its neighbors and compares the local situation to the global one (Getis and Ord 2010). Again, three different threshold distances were tested.

This tool identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). It creates a new shapefile of the dataset, with three additional fields for each record, reporting: z-score, p-value, and confidence-level bin (named Gi_Bin). The higher (or lower) the z-score, the more intense the clustering, thus considering also the p-value, the tool returns statistically significant hot and cold spots at different confidence level.
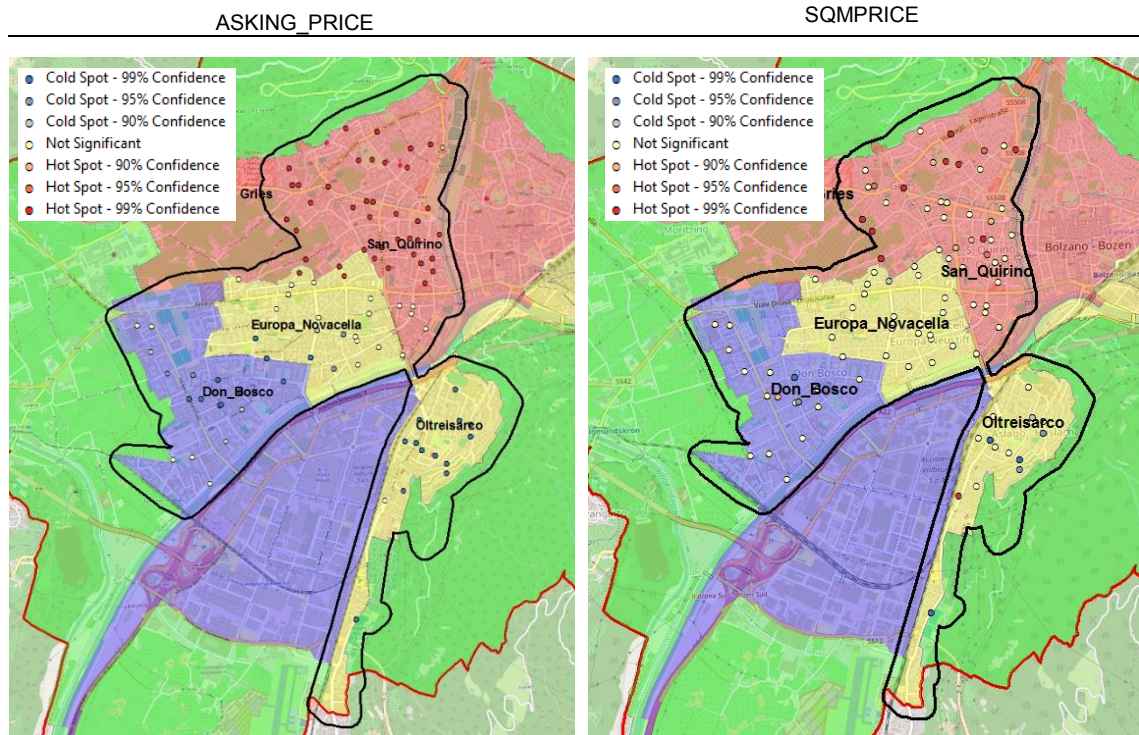
Figure 8: Hot-Spot Analysis

The maps above (Fig. 11) highlight the presence of a wide large statistically-significant "hot spots" (dark red points) aggregation in the Gries district and a large statistically-significant "cold spot" in the northern side of Aslago district (dark blue points), surrounded by "cold spots" with lower statistical significance (light blue points). Similar to the latter, other "cold spots" are found in the Don Bosco district.

4.5.6 Concluding remarks on spatial analysis

Through the General G and spatial autocorrelation tests information about the overall pattern of SMAP values in the SINFONIA district in Bolzano is obtained, and the presence of statistically significant clustering of high/low values detected. Then, through other local statistical tests, it was possible to detect areas where these clusters appear. By comparing the results of both of the local tests, we see some differences due to defining spatial weights in different ways and using different p-values, however, we can now clearly see that some clusters in certain urban areas are confirmed, and we can also attach to them a precise statistical significance. Detecting this points helps, first in revising specific record of the dataset, to double-check information reliability, second in defining the spatial-explanatory variables to be tested, and eventually included in the regression model. In particular, it is evident how the data collected in the Gries district are characterized by very high values (as it was expected, on the basis of personal knowledge and looking at the official values provided by the Observatory of Italian Tax Agency). On

the other hand, it is confirmed that the records in Oltre Isarco are the lowest in general, excluding some new buildings that are significantly lower on the northern side. It should be also considered that some values in the middle of the Don Bosco district are quite low, compared to those surrounding it and to OMI values.

4.6 Modeling strategy

4.6.1 Models developed

Various regression models are tested to investigate the relationship among property asking prices and EPC classes. The dependent variable is the natural logarithm of asking price (LOG_PRICE), as this is the usual specification, that makes possible a straightforward interpretation of coefficients (De Ayala et al. 2016). For the default spatial variable, the "Aslago - Oltre Isarco" district (ASLAGO_OLTRI) is chosen, as the lowest expected coefficient. Similarly, the poor maintenance conditions expressed as "property to be refurbished" (TBR), and "G" as worst technical characteristic related to energy performance.

Other selected characteristic can be grouped into:

- Intrinsic location characteristics, related to the position of the property within the building (LAST_FLOOR), its surface (SURF), and the number of rooms (ROOMS) and bathrooms (BATHROOMS) or the presence of additional features (BALCONY) or garden (PRIV_GARD).
- Technological characteristics here expressed basically by the heating system type (HEATING) and the EPC label. This latter is first analyzed as an ordinal variable (ABCDEF) in "Model_ABCDEF", then as groups of energy classes: premium (A_B), intermediate (C_D), and low (E_F) (i.e. a set of dummy variables) in "Model_AB_CD_EF".

Productive characteristics are not included, as all the properties are for sale (i.e. advertisements transferring only the "nuda proprietà" right - in english "bare owneship" - were discarded in the selection phase). The main purpose of "Model_ABCDEF" specification is twofold: first to define the most interesting variables to be included in the regression, and second to verify whether or not, in our sample, the trivial positive relationship between ASKING_PRICE and ENER_CLASS appears, and if it is statistically significant. The following Table 7 offers a comparison between the two models.

Variable	Model_ABCDEF				Model_AB_CD_EF			
	Coef.	Std.Er.	Signif.	VIF	Coef.	Std.Er.	Signif.	VIF
Intercept	11.27369	0.035659	***		11.288887	0.035202	***	
SURFACE	0.007236	0.000362	***	3.9	0.007228	0.000363	***	4.0
NEW	0.280725	0.0434	***	3.8	0.263986	0.04384	***	3.9
VERY_G	0.195192	0.025017	***	4.1	0.193469	0.024952	***	4.1
GOOD	0.116319	0.024721	***	3.8	0.115449	0.024653	***	3.8
GRIES	0.356077	0.024301	***	1.3	0.352854	0.02429	***	1.4
SAN_QUIRIN	0.234202	0.021128	***	1.3	0.231715	0.021065	***	1.6
EUROPA_NOV	0.152991	0.017215	***	1.2	0.153361	0.017153	***	1.5
DON_BOSCO	0.110471	0.019104	***	3.9	0.10704	0.019107	***	1.4
LAST_FLOOR	0.02435	0.022831		1.0	0.023113	0.022781		1.1
A_B					0.091699	0.0342	**	3.0
C_D					0.060702	0.03143	*	1.2
E_F					-0.045796	0.033616		1.0
ENER_CLASS	0.013252	0.00575	*	2.9				
HEATING	0.005233	0.014717		1.1	0.003806	0.014832		1.2
ROOMS	0.055897	0.010795	**	3.0	0.056131	0.010775	***	3.0
BATHROOMS	0.055821	0.018477	**	1.9	0.057731	0.01847	**	1.9
BALCONY	0.079813	0.015882	***	1.2	0.079587	0.015845	***	1.2
GARAGE	0.006604	0.012933		1.3	0.007069	0.012885		1.3
PRIV_GARD	0.058846	0.023254	*	1.2	0.053775	0.023551	*	1.3
R2	0.856				0.857			
Adj-R2	0.852				0.853			
Log-likelihood	290.643				293.66			
AIC	-547.3				-549.3			
Observations	650				650			

*,** and *** indicate significance levels of 5%, 1% and 0.1%, respectively

Table 5: OLS estimation

Almost all selected variables are statistically significant in both models, except the fact of location on the top floor (LAST_FLOOR), having a garage (GARAGE), and the specification of the heating system (HEATING). The variable "energy-performance class" (ENER_CLASS) is significant and with a positive sign, therefore the starting hypothesis is overall confirmed by our sample. Both models perform similarly, explaining nearly 85% of the variation in the dependent variable. By comparing the results, the statistics also suggest a preference for the more detailed model, with higher the log-likelihood and lower AIC, although having more variables (about the use of AIC in model selection, see for example Snipes et al. (2014)). Neither were large Variance Inflation Factor (VIF) values, indicating redundancy among explanatory variables, detected.

4.6.2 Spatial autocorrelation tests

Both models are first estimated by the ordinary least-squares method (OLS), and then are tested for spatial autocorrelation, which may arise due to missing independence among observation, a situation not difficult to imagine in an intra-district or inter-neighboring district context. Disregarding spatial autocorrelation leads to inconsistent and biased parameters in a hedonic price function (Anselin and Bera 1998; Herath et al. 2015). Spatial autocorrelation is tested with regard to the three distances (1,000, 1,500 and 2,000 mt) following the approach defined by Herath et al. (2015). If spatial autocorrelation were found, the selection of modeling strategy will be conducted following the decision rules explained in Section 2.

				Spatial weight threshold					
Model_ABCDEF		1,000 mt			1,500 mt			2, 000 mt	
TEST	MI/DF	Value	Prob	MI/DF	Value	Prob	MI/DF	Value	Prob
Moran's I (error)	-0.008	-1.717		-0.0007	-2.330	*	-0.004	-4.737	***
LM (lag)	1	0.0452		1	2.2076		1	9.25	***
Robust LM (lag)	1	0.2673		1	1.1152		1	7.5178	**
LM (error)	1	0.4539		1	1.2583		1	2.0285	
Robust LM (error)	1	0.6759		1	0.1659		1	0.2963	
Model_AB_CD_EF		1,000 mt			1,500 mt			2, 000 mt	
TEST	MI/DF	Value	Prob	MI/DF	Value	Prob	MI/DF	Value	Prob
Moran's I (error)	-0.006	-0.700		-0.008	-2.647	**	-0.004	-4.285	***
LM (lag)	1	0.007		1.000	1.993		1.000	10.495	**
Robust LM (lag)	1	0.090		1.000	0.853		1.000	8.824	*
LM (error)	1	0.237		1.000	1.436		1.000	1.830	
Robust LM (error)	1	0.321		1.000	0.295		1.000	0.159	

*,** and *** indicate significance levels of 5%, 1% and 0.1%, respectively

Table 6: Tests for spatial autocorrelation

Concerning spatial autocorrelation of residuals (Moran's *I*), both models always pass the test (large p-value), except in the case of a spatial- weight threshold equal to 2,000. However, in this case, the index is close to zero, thus spatial autocorrelation is not a serious problem. For the sake of completeness, the results of Spatial Lag specification is reported in the following Table 9.

Variable	Spatial Lag Model_ABCDEF			Spatial Lag Model_AB_CD_EF		
	Coef.	Std.Er.	Signif.	Coef.	Std.Er.	Signif.
Intercept	12.9791	1.88902	***	13.3993	1.89617	***
SURFACE	0.007275	0.0003593	***	0.007278	0.0003601	***
NEW	0.281399	0.0428076	***	0.264684	0.0431556	***

VERY_G	0.194622	0.0246816	***	0.192718	0.0245718	***
GOOD	0.115043	0.0244244	***	0.113833	0.0243135	***
GRIES	0.383956	0.0388664	***	0.387184	0.0388369	***
SAN_QUIRIN	0.253588	0.0298822	***	0.255587	0.0297991	***
EUROPA_NOV	0.169811	0.0250505	***	0.174184	0.0250683	***
DON_BOSCO	0.121302	0.0224228	***	0.120271	0.0223628	***
LAST_FLOOR	0.024166	0.0225175		0.022838	0.0224258	
A_B				0.090729	0.0336719	**
C_D				0.060991	0.0309376	*
E_F				-0.050338	0.0333422	
ENER_CLASS	0.013252	0.005750	*	0.0047229	0.0146258	
HEATING	0.005233	0.014717		0.0564129	0.0106087	
ROOMS	0.055897	0.010795	***	0.0559058	0.0182480	***
BATHROOMS	0.055821	0.018477	**	0.0794567	0.0155969	**
BALCONY	0.079813	0.015882	***	0.0075174	0.0126886	***
GARAGE	0.006604	0.012933		0.0515521	0.0232715	
PRIV_GARD	0.058846	0.023254	*	0.0047229	0.0146258	*
λ	-0.136711					
Log-likelihood	291.05			294.28		
AIC	-546.1			-548.6		
Observations	650			650		

*,** and *** indicate significance levels of 5%, 1% and 0.1%, respectively*

Table 7: Spatial Lag Model estimation

Not surprisingly, the lag coefficient (λ) is not significant, and the estimated parameters are almost the same as in the OLS model, that, in this case, results in appropriately solving the hedonic price equation.

4.7 Main findings and discussion

The exclusion of advertisements reporting "EPC under development" nearly halved the dataset, but contributes to eliminating an original sin of similar studies, due to the bad (at least Italian, to the best of our knowledge) habit of labeling the properties G before the proper energy assessment. On the basis of 650 spatially geolocated and analyzed data, it now appears clear how EPC classes have a heterogeneous distribution within the SINFONIA district, and, in general, how properties labeled other than G account only for 19% of the sales announcements. A and B are respectively 34 and 35, while D and E are the less populated classes. In some districts, the high-level classes are almost neglected

(as in Europa-Novacella), and, in general, there is much room for improvement of the energy performances of existing residential building stock. The evaluation of the marginal contribution of EPC in the definition of the asking price has been calculated estimating the hedonic price equation. The OLS regression was confirmed, after checking for spatial autocorrelation and testing the Spatial Lag model (the GIS software ArcMap and GeoDa were used). Results obtained by applying the EPC class as an ordinal variable indicate a 1.4% increase in asking price for each increment in the energy- performance label. This means that a standard apartment (90 m^2 in Europa district) will gain about 18.000€ value, moving from G to B, and 22.000€ to A (8.3% of the initial price equal to 273.000€). By running another model, grouping the EPC classes differently from G into three levels (E and F, C and D, A and B) and keeping all other variables the same, we obtained more detailed results for the mid- and high-energy performance buildings. This second model returns a 6.3% price premium, moving from worst class G to middle classes (C and D), and a 9.5% if reaching the best classes A and B, *ceteris paribus*. These first findings, summarized in Table 10, are comparable with those reported in similar European studies on this topic, reported in Section 3.

Model_ABCDEF							
EPC class	G	F	E	D	C	B	A
Price (mq)	€ 3,033	€3,074	€3,115	€3,156	€3,199	€3,241	€3,285
Premium (€)	-	€ 40	€ 81	€123	€165	€ 207	€251
Premium (%)	-	1.3%	2.7%	4.1%	5.4%	6.9%	8.3%

Model_AB_CD_EF				
EPC class	G	E or F	C or D	A or B
Price (mq)	€ 3,115	Not statistically significant	€ 3,311	€3,412
Premium (€)	-		€196	€296
Premium (%)	-		6.3%	9.5%

Table 8: Price premium on a standard apartment gained by EPC class improvement

The use of asking instead of transaction prices in defining the HPM is supported by the literature (Bonifaci and Copiello 2015; Bottero et al. 2014; Herath et al. 2015); sometimes also owner self-assessed values are used (De Ayala et al. 2016; Won Kim et al. 2003). Thus, referring to the asking price is not problematic, because: (i) as confirmed by local experts, the room for bargaining in the local market is very narrow, and, (ii) the purpose of this study is precisely to offer an interpretation of whether and how energy-efficiency issues are considered in asking-price formulation, also integrating their spatial variation across the urban space. The coefficients found also confirm the hypothesis related to the distribution of prices in the different districts, and the positive relationships with the

existence of additional characteristics, such as balconies or private gardens. Surprisingly, in a dense city like Bolzano, surrounded by mountains, the top-floor location, and presence of a garage, although positive, are not statistically significant. Also, the heating system type seems to be not relevant in price definition, as the specification of low EPC classes E or F. To increase the reliability of results, the overall model needs a fine tuning: given that this study has focused on collecting the energy data, additional property characteristics should be further investigated to better explain the data. For example, the existence of a double garage was removed from the model due to conflicting results, probably related to the unclear specification of some advertisements (i.e. it was not possible to definitively state whether the price of the garage was already included in the offer price or not, and similarly in calculating the surface). The test for spatial autocorrelation confirmed the efficiency of the OLS models, explaining about 85% of the dependent variable. According to similar studies, a further step to be tested is the definition of a model considering various other spatial characteristics. An option could be to specify the distance of the property from the city center (CBD), calculated on the specific address, or on the contrary, placing all the advertisement in the centroid of the district. In this way, a deeper spatial analysis, considering spillover effects and spatially lagged omitted variables, may deserve interesting results. According to Chapter 3's findings, estimates provided by this study are suitable to contributing to the assessment of the socioeconomic impact of a large-scale project. In particular, the decision to run a large-scale deep-energy retrofit campaign should lead to a "good performance of a whole city, in terms of both buildings energy efficiency as well as real estate market efficiency" (Bonifaci & Copiello 2015, pg. 15), as better explained in the conclusions of this work (see Section 6.2).

Chapter 5 - A multiple benefits approach to understanding citizen priorities for deep-energy retrofitting

Currently, within each urban-regeneration project, an ambitious improvement in the energy performance of existing buildings is planned. Consequently, refurbishing the building stock should be approached as a piece of a wider, more complex project. This means no longer treating retrofitting as a mere technical problem, to be solved simply by upgrading energy systems, introducing renewable sources, or enhancing energy efficiency by adopting the latest technologies. Rather, the technological innovation of buildings should be considered not as the final goal, but as a way to improve citizens' quality of life and to meet their expectations. Thus, the key emerging question are: why are energy-efficient buildings attractive to citizens? What are the motivations driving the choice in deciding to undertake such refurbishment work? Are the economic benefits the most influential argument underpinning their decisions? Recent studies in this field suggest the relevance of motivations dealing with the health and well-being of the building occupants, environmental consciousness, the pleasure of enjoying spatial quality, and the higher evaluation by the real-estate market of energy-efficient dwellings. Thus, a better understanding of citizen awareness and preferences is necessary for the decision-making process, to avoid project failures or underperformance.

Starting from these considerations, this Chapter tackles the issues of the motivations behind the choice in asking for energy-refurbished buildings by adopting a multi-criteria approach. The decision tree is implemented following the analytic-hierarchy-process methodology (AHP), assuming the unitary relevance of a high-quality energy refurbishment as an expression of multiple benefits. By learning from previous works in this field, this complex decision is reduced to a limited, although significant, series of characteristics, grouped into criteria. Then, a panel of experts including engineers, architects, and professionals in the building sector makes a series of pairwise comparison. Finally, by aggregating expert judgments, the multiple benefits suggested by the literature are verified and weighted on a local urban market. The case study presented

here comes from the European smart-city project SINFONIA. The method sensitizes developers and decision makers to consider citizens' priorities from the early design phase up to communication strategies, contributing to a better understanding of the socio-economic aspects connected to the implementation of sustainability measures in buildings.

This Chapter is organized as follows: Section 1 introduces the topic of motivations toward energy retrofitting of buildings. In Section 2, the development of an AHP approach (a popular multi-criteria technique) is briefly illustrated. Section 3 provides an overview on the results of an investigation involving ten qualified experts. Section 4 summarizes the key findings, limits and next steps.

5.1 Buildings as a key intervention sector to reach the EU climate-energy goals

Buildings are responsible for about 40% of global energy consumption, and they emit one-third of CO_2 emissions. While these figures are also similar at the European Union (EU) level, buildings represent a key intervention sector to reach the EU climate-energy goals by 2020 and to move toward a low-carbon economy by 2050. Because 35% of the EU's building stock is over 50-years old, with very poor energy performance, "*the potential for cost-effective energy savings is about 30% of the whole sector's expected energy consumption by 2020, which would lead to significant economic, social and environmental benefits*" (European Commission, 2008). This is particularly evident if we consider that, generally, new high-performance buildings require one fifth of that of old buildings' average consumption to satisfy their energy need. Again, the Copenhagen Economics (2012) reported how "*harvesting renovation opportunities could bring huge benefits to the EU economy over the coming decades*"; it estimated "*a monetized permanent annual benefit to society of €104–175 billion in 2020 depending on the level of investments made from 2012 to 2020*".

This research, therefore, argues that, besides the "cultural" relevance, the "economic benefits" side also plays a relevant role and owners probably make several considerations, when they decide to undertake energy-retrofitting activities. Indeed, the success of the "deep-energy retrofit" approach lies in the opportunity to achieve much wider benefits (exceeding the pure energy needs and energy-expenses-related savings), by taking a whole-building approach. One can consider the "deep-energy retrofit" as a "macro" decision-making problem, which can be further decomposed into "micro"

elements, representing the various values attributed by house owners to the detailed benefits achievable by the execution of this kind of intervention.

Currently, the EU's main act addressing this topic is the 2010 Energy Performance of Buildings Directive (EPBD); it provides the legal framework for the member states to define national policies and measures to reduce the energy consumption of buildings. The EPBD, by considering the different realms for improvement in energy use for space and water heating, cooling, ventilation, and lighting, calls for the establishment of legal minimum energy-performance requirements and information-based instruments, such as energy certificates. The first must be applied to new buildings at the time of construction or to existing ones when major renovation work occurs (this means every 25–40 years approximately); the latter must be drawn up when the building is constructed, sold, or rented (and expires after ten years).

To encourage the undertaking of major renovation works, and to increase the annual renovation rate (actually 1% at EU level), member states are designing various supporting schemes. For example, in Italy since 2007, energy upgrading of existing buildings has been promoted through a related tax benefit. The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) points out how the International Energy Agency "*recently mentioned this measure as a best practice at international level, with specific reference to its role in the spreading of an energy efficiency culture at local level*" (ENEA 2015).

Since energy behaviors and public awareness may be very context-dependent, and because the city of Bolzano in northern Italy is currently experimenting with an innovative, deep-retrofitting approach through the SINFONIA FP7 smart-city project, which ultimately aims at stimulating wider renovation of the urban building stock, the local context of Bolzano and the surrounding South Tyrol province need to be further investigated. Better knowledge of citizens' expectations will enable developers and decision makers to better consider their priorities in promoting similar activities, from the early design phase up to devising tailored communication strategies. Starting from these considerations, this research devised a structured interview, focused on the multiple benefits of deep energy-refurbishment works, to gather a few significant figures concerning house-owners expectations. The problem is tackled by interviewing a pool of local experts in this field, using a multi-criteria decision analysis approach. The following Sections document an overview of the selected methodology, undertaken activities, and the results obtained, after the first round of interviews.

5.2 The multi-criteria approach

To investigate citizens' expectations, we interviewed professionals in the residential building-refurbishment sector, adopting a multi-criteria decision analysis (MCDA) approach. The MCDA methods are helpful tools in setting up problems characterized by a set of possible solutions (also called alternatives) that are evaluated on multiple points of view (usually called criteria); by including in the decision-making process all the relevant arguments and interactions, the MCDA methods enable finding compromise solutions along a rational path. In this case, the overall methodological problem of setting relative values for the expected utilities from deep energy-retrofitting interventions has followed the methodological approach defined by the Analytic Hierarchy Process (AHP), developed by (Saaty 1980). AHP is one of the most widely applied MCDA technique, often used in energy-related decision making, from planning (Pohekar and Ramachandran 2004) to indoor-comfort assessment (Chiang and Lai 2002), that helps in structuring complex decision problems in a hierarchical form. The AHP follows three main steps: (i) structuring the problem as a hierarchy; (ii) setting priorities among the elements of the same level of the hierarchy, by means of pairwise comparisons; and (iii) checking for the logical consistency of the pairwise comparisons. The AHP is usually used to compare alternatives based on a set of criteria structured as a hierarchy. However, it proves to be a powerful tool also for setting the relative importance of a set of criteria (structured but not hierarchical).

The choice of the AHP method is justified by the possibility of producing the basis for comparison, which enables evaluation of qualitative criteria through a pairwise comparison method which is easy to set up. It also enables one to work on judgments of verbally-expressed preferences through a semantic scale (Saaty 1980) and, at the same time, it takes into account the limited number of levels of judgment that the human mind can handle.

After having defined the main decision problem in the form of a complex question, the problem is detailed through a set of criteria, which are detailed via sub-criteria in turn. Through the pairwise comparisons and using the semantic scale proposed by Saaty, it is possible to assess the relative importance of criteria and sub-criteria for each respondent. For each respondent, a pairwise-comparison matrix is obtained, and its eigenvectors, whose components represent the relative importance expressed by a respondent for each criterion, are calculated. Formally, the relative importance (or 'local weight' in the hierarchical level of 'criteria') of the criteria are given by the right-hand eigenvector

corresponding to the highest eigenvalue of the pairwise-comparison matrix (Attardi et al. 2015; Saaty 1980).

Since the procedure used to express preferences does not provide for the collection of information about the absolute importance of the criteria, but only about their relative importance, there may be some inconsistencies, i.e. violations of transitivity in expressed judgments. Therefore, a check for the logical consistency of each matrix is required.

The specific rules and general recommendation recalled for the application of AHP in the literature of multi-criteria decision analysis (Ishizaka and Nemery 2013) are the following:

- the number of criteria and relative sub-criteria should be kept as small as possible, without exceeding seven, which is considered the borderline value, to enable consistent comparisons;

- the fundamental numerical scale by Saaty (1–9) should be adopted, also flanked by verbal definitions, to help respondents in expressing the degree of importance;

- the decision-tree structure and contents are formulated through brainstorming sessions, involving authors and test respondents, and, usually, analyzing similar problem studies;

- the inconsistency level of answers within each node (i.e. pairwise-comparison matrix) must always be below 10% (Saaty 1994, 1980).

Indeed, we structured the complex question (defining the possible benefits of a deep-energy retrofit) as a set of criteria (the main categories of benefits). Then each one was better specified by additional sub-criteria (detailed benefits), asking for pairwise comparisons, up to obtainment of a degree-of-relative importance between pair of them. Consequently, the decision tree was organized around three cluster levels:

- Level 1 – Goal: deep energy retrofit;
- Level 2 – Categories of the benefits;
- Level 3 – Detailed benefits of each domain.

At each level, except the GOAL, the fundamental scale of Saaty (see Table 11) expresses the degree of importance.

Degree of importance		Degree of importance		Degree of importance	
Numeric	Verbal	Numeric	Verbal	Numeric	Verbal
1	Equal	4	Moderate plus	7	Very strong
2	Weak	5	Strong	8	Very, very strong
3	Moderate	6	Strong plus	9	Extreme

Table 11: The fundamental scale of Saaty (numeric and verbal)

We asked the local public agency "CasaClima – KlimaHaus", responsible in south Tyrol province for auditing buildings' energy and certification and partner in the SINFONIA

Project, to contribute to our work by inviting its associates to join the research. As a result, during June and July 2016, we conducted eight phone interviews, collecting information from local engineers, architects, and experts in the building sector. We invited respondents to answer based on their personal and professional experiences with local customers, who ask for a "deep-energy retrofit" intervention. We established the general framework with the introductory phrase:

"Please, think about your local customers. In asking for a deep energy retrofit of their dwelling/house, what are the most relevant benefits they expected, among the following?"

As previously recounted, the set of criteria and related sub-criteria was defined on the basis of research questions and results suggested by previous studies in this field. Looking at the economic benefits, the international literature argues that monetary savings, basically due to reduced-energy needs (Krause and Bitter 2012) and lower maintenance costs of new and efficient appliances (Ürge-Vorsatz et al. 2010), are evident. Moreover, it is widely recognized how the real-estate market appreciates the green attributes of efficient buildings, translating them into price or rent premiums (Bonifaci and Copiello 2015; De Ayala et al. 2016; Eichholtz et al. 2010a). Investigating deeper the improvement of living conditions, it has been found that expected benefits come from the reduction of external noise, due to better acoustic insulation of windows (Ürge-Vorsatz et al. 2010; Jakob 2006) and the achievement of improved indoor comfort, due to thermal-bridges reduction (Jakob 2006). Acre and Wyckmans (2015) also investigate the meaning of having better spatial conditions, including the physical distribution of rooms, glazing surfaces, and daylight. Moreover, we included in our investigation a criterion related to sustainability, trying to trace the attitude of house owners to environmental issues as well as to their social behavior. Thus we explicitly mentioned the decrease of air-pollutant emission produced by energy generation and the expression of an individual green social status, due to the adoption of sustainability measures, as a benefit for themselves and an incentive for others; Dastrup et al. (2012) identified this as an expression of the "warm glow" phenomenon.

The definition of criteria and sub-criteria was later refined according to the test-phase results. We carried this out in May 2016 on five respondents having a professional background comparable to the sample. After this phase, the sub-criterion "*tax deduction*" was added under "*economic benefits*" and the sub-criteria under "*external noises*" better distinguished between "*noise disturbances from outside the building*" and "*noise disturbances from adjoining apartments*". While the specification concerning noises is self-explanatory, "*tax deduction*" deserves an explanation. This particular feature relates

to the specific national Italian construction sector, where, since 2007, energy upgrading of existing buildings has been promoted through tax benefits. The mechanism consists of the deduction from income tax of a share of the costs incurred for the energy refurbishment (actually, 65% over ten fiscal years). Beneficiaries include all taxpayers, such as individuals, professionals, companies, and other enterprises. The deductions are awarded under the condition that the intervention conforms to the standards prescribed and is certified by a qualified technician, who is held responsible by law. Eligible activities and related maximum deductions, defined by law n° 190/2014, concern the overall energy refurbishment of existing buildings (100,000€), thermal insulation of the building's envelope (60,000€), purchase and installation of solar thermal panels or solar shading systems (60,000€), and purchase and installation of new efficient-heating systems (30,000€).

Finally, as shown in Fig. 12, we obtained a decision tree with five criteria and 15 sub-criteria: four in "*thermal and hygrometric comfort*", three in "*design and architectural quality*", "*acoustic comfort*" and "*economic benefits*", and two in "*sustainability*".
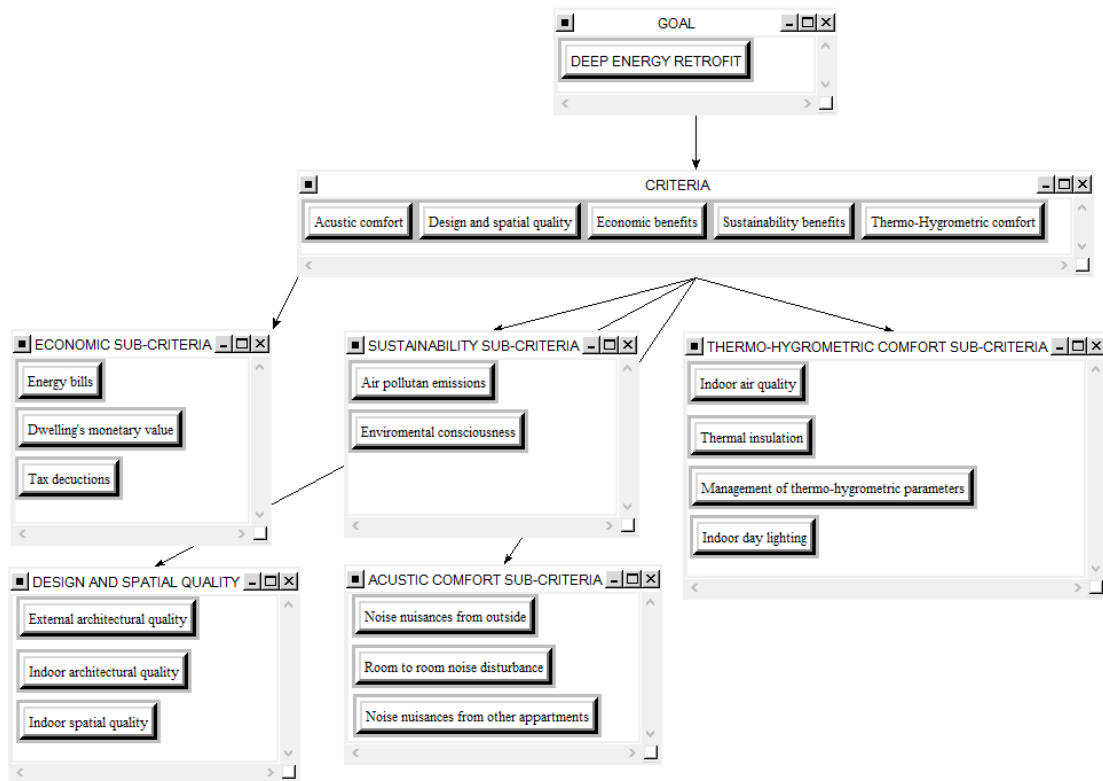
Figure 12: The decision tree of deep-energy refurbishment implemented in the Super Decision software

According to the procedures required for the implementation of the AHP, we asked respondents to express their judgments, firstly among the five criteria and then among each set of sub-criteria. Because of the reciprocity rule (Saaty 1980), the overall number

of questions required to complete the interviews was limited to 26: ten pairwise comparisons for level 2 (one matrix 5 x 5), 16 pairwise comparisons for level 2 (one matrix 4 x 4; three matrixes 3 x 3; one matrix 2 x 2). This reduces the average time required for the completion of one interview to 20–30 minutes. The results of each phone interview were simultaneously recorded in the "Super Decisions" free software, specifically developed to support the data collection and results' validation by implementing this technique (see: www.superdecisions.com). For our purpose, since we don't have alternatives to compare or rank, the most relevant feature offered by the "Super Decisions" is the inconsistency check, monitoring step-by-step after each answer the coherence of pairwise comparisons (see as an example Fig. 13).
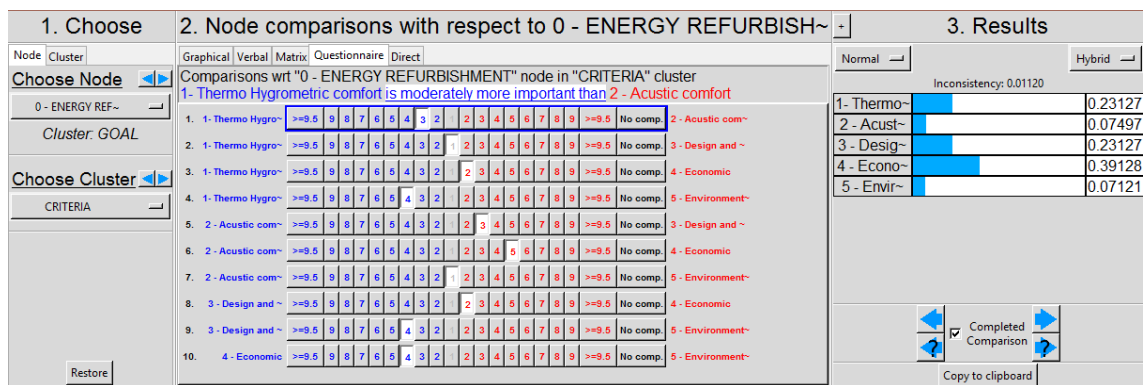
Figure 13: Example of pairwise comparison accomplished and related inconsistency check in the Super Decision software

5.3 What do citizens expect from a deep-energy retrofit

In this Section, the main results obtained by the execution of ten phone interviews are reported. The AHP approach has been used, and the sample was selected among south-Tyrolean professionals working in the residential building-refurbishment sector. The aim was to identify the relative importance (weight) of various claimed in the decision to undertake refurbishment activities and to describe the overall and individual results. All recommendations expressed in Sect. 2 for the design phase were observed and the results recorded, also by checking the inconsistency of pairwise comparisons, through the "Super Decisions" software. The main results of the survey are summarized in Table 2. The median and mean (arithmetic and geometric standardized) of the sample are similar in almost all the variables, so the center of the data seems to be not too much influenced by outliers.

Criteria	Min	1 Quart	Median	Arith. Mean	Geom. Mean (Std.)	3 Quart	Max	Var.	SD
Thermo-hygrometric comfort	7%	11%	20%	22%	21%	38%	41%	1.6%	12.5%
Acoustic comfort	6%	8%	8%	9%	10%	11%	14%	0.1%	2.4%
Design and spatial quality	5%	13%	17%	22%	21%	30%	44%	1.4%	11.7%
Economic benefits	22%	32%	38%	37%	40%	45%	56%	0.9%	9.5%
Sustainability benefits	3%	4%	6%	10%	9%	14%	21%	0.3%	5.9%

Table 12: Main figures of the survey

As graphically expressed in Fig. 14, the mean of the judgments deduced from the pool of experts assigns the first place to economic benefits (37-40%), and a remarkably similar importance both to thermo-hygrometric comfort (21-22%) and design and spatial quality (21-22%). The less-relevant values result in acoustic comfort (9-10%) and sustainability benefits (9-10%).
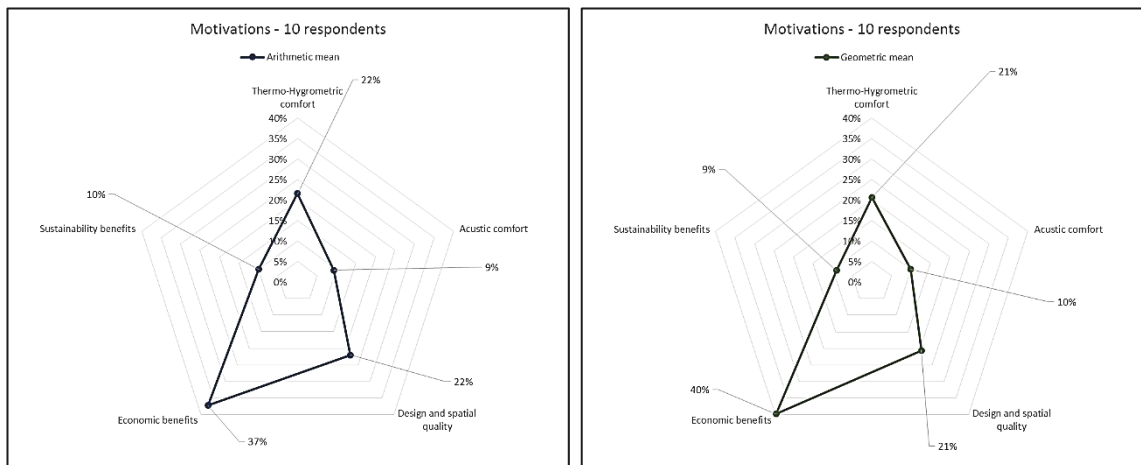
Figure 9: Overall results of weighting process from phone interviews

However, as Figs. 13 and 14 show, respondents provide varying interpretations of citizens'/customers' expectations, suggesting different profiles.
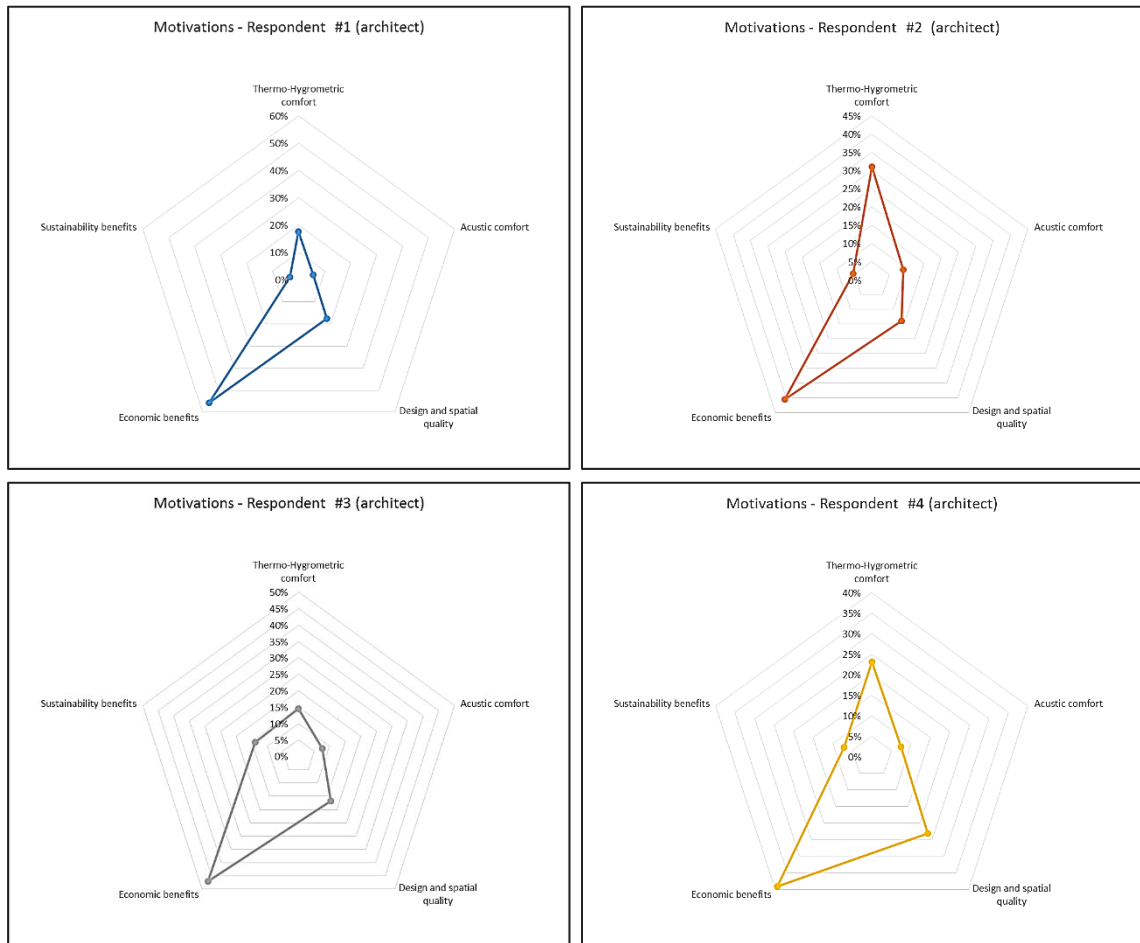

Figure 10: Individual results of weighting process from phone interviews

Weights expressed by respondent #2 remain completely within the 1st and 3rd quartile, while others exceed this interval—from one (#3, #4, and #9) to three judgments (#1, and #8). We note that the profile described by respondent #2 and #5 is very similar: they only remarkably exchange the weights assigned to thermo-hygrometric comfort and economic benefits. Also, #5 is not very different from #7, except for the lower relevance attributed by the latter to design and spatial quality. Interesting, #8 and #7 totally disagree about design and spatial quality, pointing out opposite values (the architect considers his/her customers less interested in aesthetic issues).
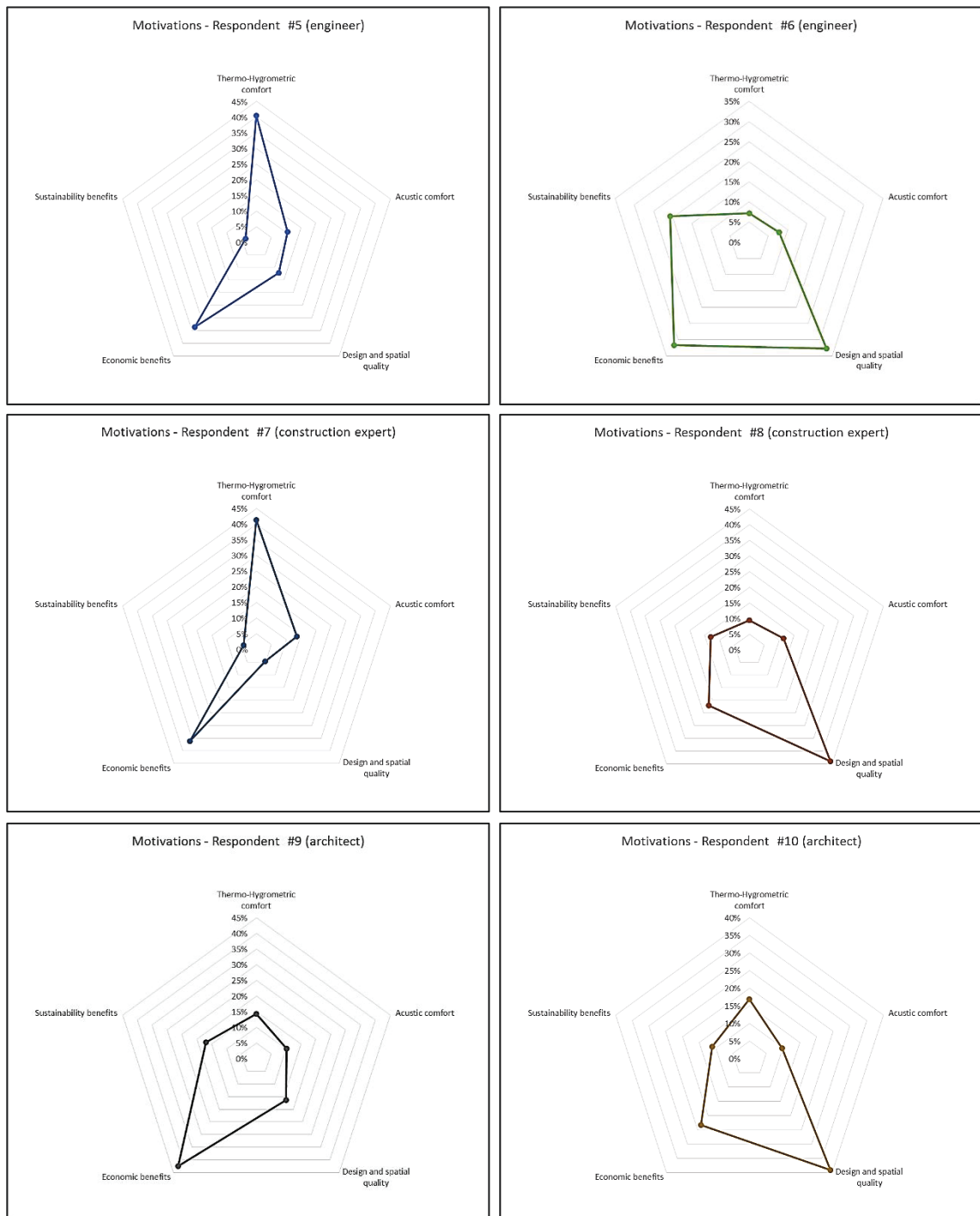
Figure 11: Individual results of weighting process from phone interviews

A deeper analysis of the relative importance attributed to sub-criteria reveals an acceptable agreement among the respondents, since values mostly converge in the majority of sub-criteria, resulting in values falling within short intervals. Only a few outliers can be found, and larger intervals concern only the "*environmental consciousness*" and "*air pollutant emissions*". The sub-criteria with the highest average value is "tax deduction"

(23%), followed by *"indoor spatial quality"* and *"thermal insulation"* (both 10%), as in Fig. 15.
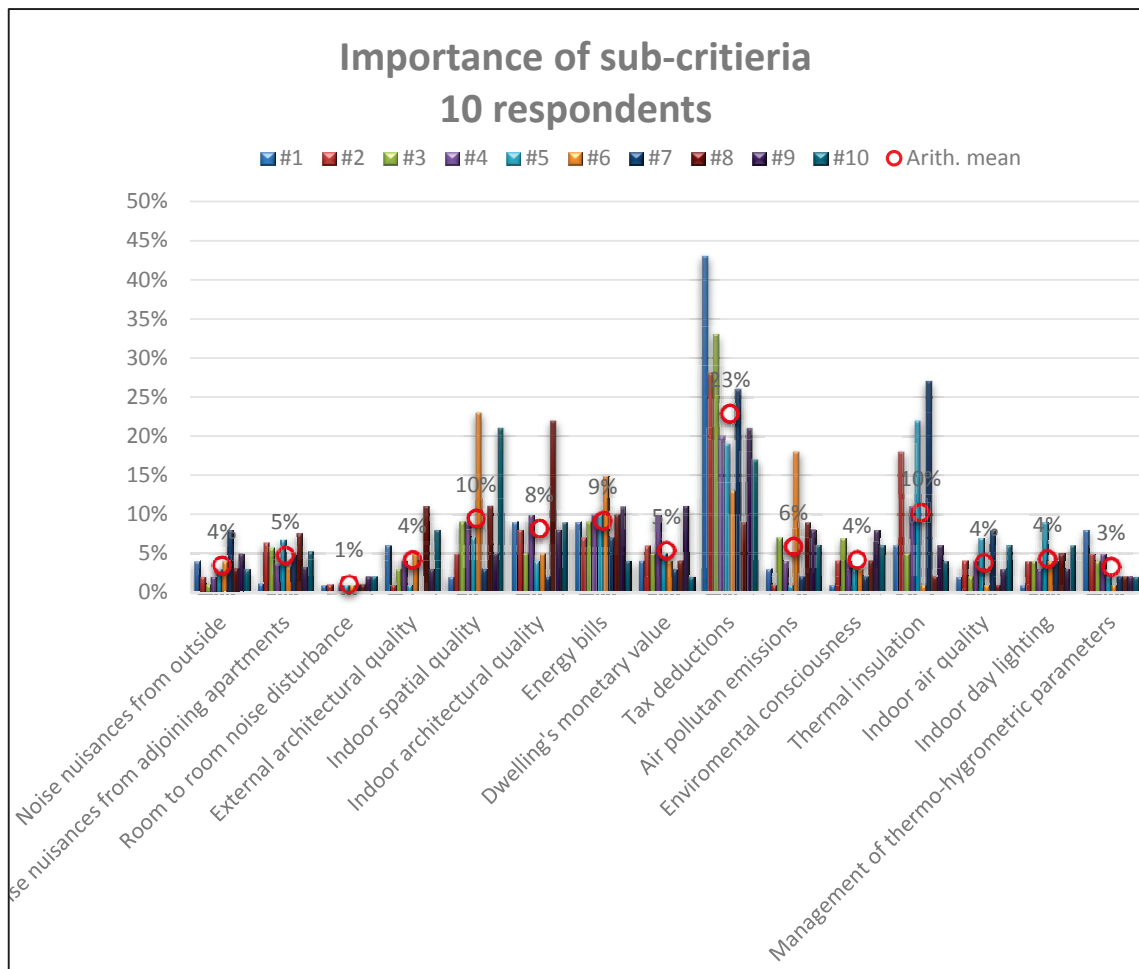
Figure 12: Individual and average importance attached to sub-criteria

Slightly below lie "*energy bills*" (10%), *"indoor spatial quality"* (9%), and "*indoor architectural quality"* (8%). The majority of other sub-criteria achieve values between only 4 and 6%, and the lower importance is attributed to *"thermo-hygrometric parameters management"* (3%) and "*room–to–room noise disturbance"* (an average of approximately 1%).

Concerning the distribution of weights among sub-criteria belonging to the same benefit (criterion), we found different scenarios:

– half of the total thermo-hygrometric comfort benefit is expected to come from better thermal insulation, with a small contribution given to the same extent by enhanced management systems (intelligent thermostats for space-heating control), technologies such HVAC (heating, ventilating, and air-conditioning

systems). More interest is given to improving glazing surfaces and shadings enabling a better daylighting;

– design and architectural quality are basically considered relevant only from the indoor perspective, and also relevant is the expected benefit of changing the spatial arrangement of rooms;

– acoustic issues are less considered, although avoiding or reducing noise nuisance from adjoining apartments is the key point in this factor;

– economic benefits are at the top of householders' expectations, and, in this particular context, the incentive of the tax deduction is the main driver (i.e. currently and during recent years in Italy), more than twice as important as monetary savings from reduced energy bills. The expected increase of value related to better energy performance is the lesser-perceived economic benefit;

– sustainability benefits related to pollutant-emissions reduction are slightly stronger than the desire to be a positive example for the neighborhood (i.e. personal gratification for shifting to a greener lifestyle).

Looking at values attributed by individual experts, we found a higher score (over 15%) for sub-criterion *"thermal insulation"* by respondents #2, #5 and #7, over *"air pollutant emissions"* and *"indoor spatial quality"* sub-criterion by #6 and for "*Indoor architectural quality"* sub-criterion by #2.

Besides attribution of priorities, respondents also took the opportunity in the interview to comment on some questions and to express interesting remarks. Table 13 reports the most relevant, contributing to shedding light on arguments behind numeric values.

Resp.	Remarks
#1, #4, #5, #7, #8	There is an extremely high level of complexity and uncertainty expressed by the social environment of the apartment building. Householders belonging to different ages, social statuses, or income brackets have different expectations, time horizons, or spending capacities. This heterogeneity of interests toward the refurbishment investment conflicts only with the legal need to achieve a majority to approve the working plan and even more with the real possibility of some householders affording additional expenses. Therefore, in fact, not only the majority but also the 100% consensus should be reached (#7) and the unique argument considered is often the final cost (#8). Consequently, in most of the cases, the intervention on the apartment building is only external, on the facades or roof. The single flats are not involved in refurbishment activities, also because occupants are unwilling to move out for some months or to bear discomfort and the hassle.
#1, #7, #8	The relevance of external noise nuisance, in most of the cases from road traffic, widely varies in a different context and is very place-specific. Therefore, it is hard to estimate it on average and in the abstract (#1). However, there is growing interest from the general public about this (#7).
#5	Having better daylight inside the flat is often a desire, although not easy to achieve in the condominium, where permission to change windows' dimension or position is difficult to obtain. On the contrary, in single-house refurbishment, where possible, an increase in transparent surfaces is often required and realized.

#3, #5, #8	There is a growing interest from the general public in having better indoor air quality, besides the specific cases of particular disease (asthma or mold allergy) requiring high hygienic conditions (#3), even if these kind of systems are quite unknown by the general public and their operation requires behavioral changes by occupants that are very difficult to be accepted in the residential market (i.e. to avoid opening windows frequently) (#5). Similarly, thermal-management systems are sometimes too fancy for unskilled users (#8).
#4, #5	The necessity to undertake aesthetical refurbishment activities on the facades, basically repainting them, may act as the driver stimulating more complex work, also involving the thermal insulation, by changing windows or by applying exterior insulation (#4). Nevertheless, the apartments are often in very bad thermal-comfort condition, therefore improving the energy performance and solving thermal bridges turns out, in the end, being more relevant than improving the external appearance of the building (#5).
#1, #4, #5, #7	The economic benefit of the tax deduction is the main argument underpinning the decision to undertake relevant works. The main threat is that, once it has been done, the system is in danger of collapse if the environmental awareness of citizens is not adequately rooted (similar to the Italian PV market, that, after brilliant growth sustained 2008–2013 by the feed-in tariffs, is now suffering and stagnant). Unfortunately, sustainability and environmental benefits are currently perceived as "a drop in the ocean" (#4), due to the inequality between the air-pollution reduction achievable by a single home in comparison and the amount of emissions generated by other local sources (e.g., the road transportation on the street next to the house). In fact, there is a lack of perception of positive cumulative effects at urban scale and "only single house owners consider sustainability and environmental issues" in the decision-making process (#1), and those very interested in it are "a niche in the market, and mainly based in the countryside" (#5), while, for most of the people, it is "optional" (#7). Therefore, although environmental consciousness seems to be not so relevant in driving the decision to invest, this point should be not neglected in approaching the problem.
#7	The tax deduction is a real motivation only for those having enough income. Low-income or retired people can´t benefit from it, and therefore they are much more against works on common spaces in the condominium.
#7	In South Tyrol, the building law enables a volumetric increase of refurbished buildings, achieving the required energy performance (up to 200-cubic-meters bonus for residential buildings below 1,000 cubic meters, or up to 10% of larger buildings). In most of the cases, a single house reaches a 150 cubic meters bonus, which in fact is an increase in the building's value.
#4	Acoustic refurbishment of existing buildings is perceived as much more complicated than thermal refurbishment, due to the lack of diagnostic tools, enabling the designer to investigate and discover technical weaknesses (i.e. there isn't something comparable to a thermographic camera, which shows where thermal bridges are).
#4, #5, #7	Overall, there is a lack of a long-term vision, and the ability to compare the immediate expenditure with the advantage of a constant flow of future monetary savings or the expected increased property value on the market, which is currently still difficult to estimate. People investing in deep-energy retrofitting are willing to stay longer in the refurbished house; therefore, they don't consider a possible increase in the selling price nor its asset value (#7).
#4	Concerning the architectural and spatial features, customers are willing to spend more for increasing the indoor quality, with high-value products, instead of the external appearance of the building, although this last point may be considered as a way to show others how they are "going to live greener" in a highly energy-efficient house.

#8	In South Tyrol, due to severe winter conditions, the reduction of space heating bills is a strong motivation for undertaking energy refurbishment, while this is less important in milder Italian regions.
#8	In general, customers tend to prefer the installation of technical systems for cooling, instead of designing adequate passive solutions (e.g., shadings).

Table 13: Comments and remarks by the respondents of the phone interview

5.4 Key findings and discussion

The analysis of the results reveals that among experts there is an overall agreement (<2% std. dev.) on nine sub-criteria, in particular those rated to acoustic issues. More debatable are values concerning external or indoor architectural quality, and spatial quality. Interestingly, the larger disparities (9% std. dev.) concern "*tax deduction*" and "*thermal insulation*" sub-criteria, which are also the sub-criteria with the highest average values.

By decomposing the "deep-energy retrofit" into "micro" elements, the research confirms, on one hand, how the "economic-benefits" side plays a relevant role in the decision to undertake a deep-energy retrofit (38% of the global importance), while, on the other hand, it reveals how house owners only less seriously considered other potential benefits, such as the acoustic-insulation improvement (9% of the global importance).

Similarly, other elements positively contributing to the indoor comfort, such as better air quality or improved daylight, are not fully understood. There is a need to increase citizens' awareness about the possibility to adopt the whole-building approach in refurbishment activities, achieving multiple benefits, and to find other management and business models to approach the complexity expressed by the social environment of the apartment building or by certain types of buildings (Antoniucci et al. 2015). To support this, "cultural" and "educational" activities should be more envisaged, also to stress the cumulative positive environmental effect of a multitude of single interventions, currently underestimated (9% of the global importance). Similarly, citizens' need to familiarize themselves with the technological innovation in buildings possible today and to appreciate how they can improve the quality of life given by better indoor comfort. Otherwise, this will not be fully accepted and exploited. The acoustic design probably needs a deeper investigation also from the experts' side because currently, they consider this as uncertain in potentially-achievable results.

Going beyond the original five main criteria postulated in the design phase, it is possible to stress how relevant is for citizens the cumulative result of expected benefits dealing with better health and well-being of occupants: its value cover the 41% of the overall motivation, as shown in Fig. 16.
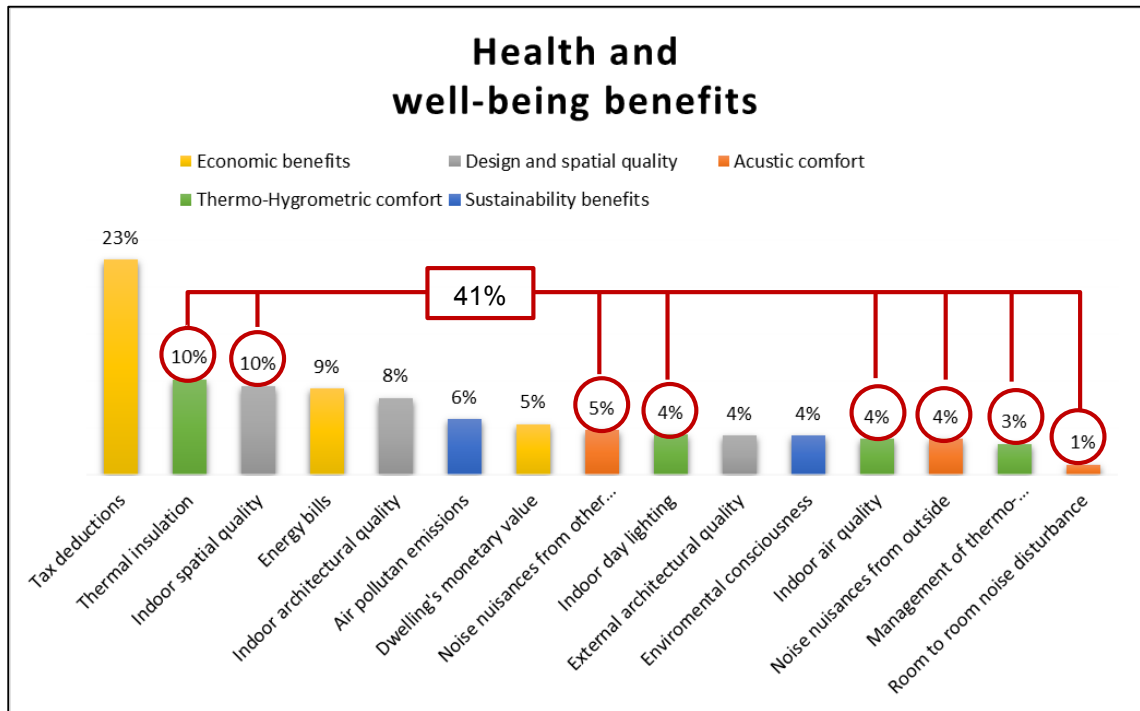

Figure 13: Health and well-being expected benefits

This finding is also in line with results of the investigation carried out in Chapter 2 of this work: in fact, the co-benefit "health and well-being" is among the top three co-benefits named by demonstration projects dealing with deep-energy retrofit of existing houses. This and other above-mentioned points should be carefully considered not only in the design phase of the projects but also in the communication strategies and within each participatory phase, modifying the way to promote and claim the project, according to the specific type of stakeholders involved.

There is also room for improvement in the experimental design: one additional field of investigation could be the co-benefit of remaining in a familiar place, saving the trouble of changing dwellings and neighborhoods, and preserving the local social capital (OECD 2001). Although there may be even more interesting arguments, any increase in the overall length of the interview and in the number of pairwise comparisons deserves careful consideration. Moreover, the results of this survey should be considered as a picture of a particular context at a certain time: weights currently assigned by experts in South Tyrol may be useful to interpret the decision-making process only of the local population and to define specific strategies, while the legal framework does not change. Any inference of

applicability within a larger population or in other places may be lead to biases in the priorities. However, on the other hand, the methodological approach and the experimental design can be replicated in other contexts and to sustain the design phase of smart-city projects.

Chapter 6 - Conclusions

6.1 Achieved results

Smart and Sustainable Energy-District projects (SSEDPs) are a preview of what our cities are going to be in the next few years. They offer the opportunity to test in the real world cutting-edge technologies and innovative approaches to make the energy transition to clean and renewable resources smoother and faster. Nevertheless, to be fully understood and supported (by stakeholders and local decision makers), and to be best devised by researcher and technicians, they must be framed within an adequate assessment scheme, beyond merely to their contributions to CO_2 emissions reduction and energy savings. Also, it should be not overlooked that high-level policy debate and scientific research take seriously the climate-energy issues on the global scale, while citizens are more interested in more immediate arguments, dealing directly with daily well-being and the quality of life.

Thus, introducing the co-benefits paradigm into the assessment approach deserves careful consideration, as this thesis shows. This is a straightforward way to, on one hand, look at the project in all its positive impacts and regard them as goods, and, on the other hand, to involve citizens, tenants, and house owners in matters of interest to them. Based on this consideration, and trying to unlock the SSEDPs full potential, this work addresses the co-benefits topic starting from a general perspective and finishing with a detailed operationalization, including examples.

The first result achieved, reported in Chapter 2, is the definition of a short list of 19 recurrent positive impacts, as noticed arising from European experiences, innovatively encoded into the smart-city development approach. To this end, the co-benefits declared by two of the most relevant European initiatives in the field of large-scale urban energy-refurbishment intervention, namely "Concerto" and "Smart Cities and Communities", are analyzed. A four-step investigation technique is used, which first extracts a raw list from official open-access sources, second defines a short list of key elements, third relates such elements to projects activities, and finally rearranges the data within the smart-city framework. In particular, most recurrent, expected effects are the creation of new jobs

related to projects execution, an increase of health and well-being due to improved indoor conditions in dwellings, and the development of stronger energy-environmental awareness among stakeholders. Additionally, the research stresses the relevance of the so-called "soft measures" related to actions by stakeholders in the co-benefits generation (and thus in the achievement of smart-city status), flanking the "hard measures" directly related to the retrofitting of buildings and updating their energy systems.

The second research step, explained in Chapter 3, contributes to answering the question whether co-benefits are so relevant that they can largely offset the cost of project development and execution, or if they are so small that they can be safely ignored, simplifying a complex project assessment (Krupnick et al. 2000). Results suggest that studying additional outcomes of SSEDPS is paramount to realizing their total multiple impact on human environment. At the same time, estimating their economic value enables researchers to evaluate welfare effects and to foresee the effectiveness of public interventions aiming at contributing to smart-city development. Thus, the value of tangible and intangible assets created by the project must be properly measured, to develop robust assessment methodologies. To this aim, by reviewing reference studies, a so-called "assessment menu" was designed that identifies what values were found, where and how the specific monetization techniques were applied, or what techniques can be suggested by analogy to investigate a certain co-benefit.

In Chapter 4, the focus shifts from the general co-benefits approach towards one specific investigation: the expected increase in property value related to the improvement of energy performance. According to Chapter 3's findings, a hedonic price method is adopted, defining an equation that decomposes the property value into a sum of marginal values, determined by intrinsic and extrinsic characteristics. The study, conducted in 2016 in the Italian city of Bolzano, demonstrating how, *ceteris paribus*, the better the energy performance class, the higher the property value. Indeed, this study addresses two weaknesses often affecting similar studies. The first is determined by the lack of reliability of the information provided by sales advertisements concerning the energy-performance class (at least in Italy). The second is the poor consideration of spatial relationships and investigation of spatial dependence, leading to biased OLS estimates. Conversely, in this case, the result is achieved after removing potential bias in the sample and testing ordinary least squares (OLS) results for spatial autocorrelation. Analyzing a sample of 1,130 geolocated sales advertisements, statistically significant positive correlation is found between intermediate (C or D) energy classes and the offering prices. For higher classes (A or B), the price premium growth increased by 9.5% compared to the worst

class "G". The opportunity to implement spatial models, explicitly considering the presence of hidden and spatially related variables among explanatory variables (spatial-lag) or in the error term (spatial-error), is considered by the study. Although not relevant in this specific case, it opens up opportunities for further elaborations and different spatial specifications of geolocated advertisements.

Chapter 5 triggers the investigation of the estimation of co-benefits, assuming the view-point of a specific target group. Leaving aside the planetary climate-energy-related issues necessitating more energy efficient buildings, the investigation aims to offer a better understanding of the motivations (i.e. the expected benefits) declared by householders. By using a popular multi-criteria technique, the analytic hierarchy process (AHP), the main goal of having a deep-energy retrofitted building is decomposed into five families of criteria and sub-criteria. Interviewing a panel of ten local experts, the research finds how strongly interested South Tyroleans are in achieving "economic-benefits" (38% of the global importance). This result is not surprising, considering the national legal framework that strongly subsidies with tax credits such renovation works. More interesting is the low consideration for the related positive environmental effects (9% of the global importance), due to a lack of a broader vision, specifically when considering a multitude of single interventions, and the lack of financial and management models that might foster the whole-building approach, especially in multifamily buildings. What clearly emerges is also the weight played in the decision-making process by expected benefits that can be grouped under the label "health and well-being". On the other hand, to increase the quality of life and achieve better indoor comfort, occupants need to familiarize themselves with the technological innovations now possible in residential buildings, removing cultural barriers and preconceived notions that still today hinder the implementation of available technologies. To support this latter goal, cultural and educational activities should be implemented more comprehensively.

6.2 Further developments

In this work, it has been demonstrated how assuming the co-benefits paradigm for the description, investigation, and classification of the positive impacts arising from the development and implementation of Smart and Sustainable Energy-District projects is a feasible and effective way to create a bridge between a major topic emerging in the climate-energy debate and the latest smart-city approach, introduced in the context of urban (re)development strategies. Further development is obviously desirable and needed to make this assessment model more robust and reliable. The results of the

investigation reported in Chapter 2 indicate a lack of co-benefits attributable to the "smart mobility" dimension, mainly due to the meager emphasis devoted to it in the very first studies. Since then, several smart energy-district projects have been developed and now they are delivering the initial results, e.g., research reports or already implemented activities, including some in the mobility sector. As Nicholls et al. (2012) state: *"the language varies - 'impact', 'returns', 'benefit', 'value' - but the questions around what sort of difference and how much of a difference we are making are the same"*. Subsequently, conducting a second iteration of the survey, more focused on the most recent projects, will be helpful in amending the key urban co-benefits list and updating the reference framework.

In Chapter 3, by designing the "assessment menu", it has become evident how a deeper investigation of the "soft measures" assessment techniques is needed to complete the general picture. Although the relevance of intangible co-benefits is widely recognized, translating them into monetary values is challenging. Nevertheless, this is a crucial point also stressed by the European Commission (2013) when emphasizing that "*besides relevant investments in deep retrofitting of housing or the development of powerful integrated energy, transport, and ICT infrastructures*" smart-city transformation requires fostering the knowledge economy. Therefore, appropriate indicators and assessment methodologies should be adopted to measure the value of tangible and intangible assets created by the projects and comparisons with the alternatives. Also, non-market techniques could help to incorporate them into a CBA or cost-effectiveness analysis. Or, changing the assessment approach, their weight should be clearly defined when developing a decision-support system based on multi-criteria decision analysis aiming at defining smart-city strategies.

Chapters 4 and 5 submit the first two attempts of fieldwork concerning co-benefits investigation. Both types of research have been conducted in a well-defined context: the spatial hedonic price considers the case study of the city of Bolzano and the multi-criteria analysis investigates behaviors in the province of South Tyrol. Any direct inference of applicability to other places or within a different population may lead to biased results: however, they are an interesting benchmark for comparisons with other case studies because the methodological approach can be replicated in other contexts. There is also room for improvement in the experimental designs, refining the sample, or expanding the analysis to include additional explanatory variables or criteria. However, an interesting direction to further develop these studies is a mixed investigation method, where both tools are combined to contribute to the assessment of the socio-economic impact of large-

scale projects or deep-energy retrofitting campaigns. Indeed, the marginal implicit price of macro variables, such as energy efficiency or the maintenance condition of the residential property, can be flanked by multiple benefits belonging to different aspects concerning health, well-being, and quality of life contributed by surrounding public spaces or the availability of environmental goods. The weight of these micro variables can be calibrated in cooperation with a larger panel of local experts (e.g., real estate agents, social housing managers, and building-sector professionals) and citizens to validate the model assumptions (see, for example, D'Alpaos et al. 2002). By linking the results of HPM and AHP to additional geolocated information (e.g., those provided by the SINFONIA project concerning the age of buildings and estimated energy consumption), it will be possible to perform a mass appraisal. By isolating houses and dwellings from the entire existing building stock and knowing the respective energy needs, it will be possible to estimate the expected positive impact on their values related to the improvement of their technological characteristics and energy performance, as well as by ameliorated surrounding public spaces, innovative infrastructures, or services.

Because of the complexity of smart city and smart-energy district projects, the new opportunities and challenges made possible by an enormous amount of data, the so-called big data, and the changes in people habits introduced by internet-connected devices or by enhanced energy efficiency (i.e. the rebound effect), an even more integrated evaluation framework is needed. This means, on the one hand, to take a holistic approach to the issues being evaluated, and, on the other hand, to be capable to create mixed assessment tools, where coupling various approaches delivers synergies. Obviously, criticalities must be considered, to avoid disproportionality between the effort needed and the reliability and usefulness of the results. Thus, better understanding citizen needs, expectations, ambitions, and priorities (by mixing the multi-criteria method with non-market valuation techniques) could be the key to success for a project and for the whole city, especially in an era of uncertainty and scarcity of resources.

The above-mentioned suggestions are only a few of the possible research paths related to co-benefits investigation. They simply point out that further research is needed in this field to sustain the adoption of the co-benefits paradigm into the assessment phases of Smart and Sustainable Energy-District projects, enabling the transition of urban areas into better places to live, and also to better understand the value of innovation introduced by disseminating ICT within buildings, infrastructures, vehicles, and social interactions.

Chapter 7 - References

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