Lecture Notes in Civil Engineering

Alessandro Marucci
Francesco Zullo
Lorena Fiorini
Lucia Saganeiti *Editors*

Innovation in Urban and Regional Planning

Proceedings of INPUT 2023 - Volume 2

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Lorena Fiorini · Lucia Saganeiti
Editors

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Dedication

These volumes are the result of the collection of papers from the 12th International Conference on Innovation in Urban and Regional Planning (INPUT2023): "Working for sustainable soil management and the role of land planning" and they are a tribute to the memory of Professor Bernardino Romano, who passed away prematurely on 1st September 2023, just before the conference took place. INPUT 2023 was possible due to his foresight and recognition in the academic world.

Prof. Bernardino Romano has been a full professor of Urban Planning at the University of L'Aquila. He had considerable influence on the development of his subject over a period of more than 30 years and provided much support to a generation of researchers and colleagues.

Since the beginning of his academic career, Prof. Romano has dedicated himself to the study of the relationship between the natural and built environment. He has been passionate about the issue of protected areas and ecological networks, expanding the existing meaning of concepts such as biopermeability and environmental continuity. In the eighties, he has been one of the first promoters of the institution of the main parks in Central Italy. His commitment in this direction was both academic and personal, through an intense activity at top level with the World Wide Fund for Nature (WWF) and the Italian Alpine Club (CAI). During these years, he has developed studies on land planning tools aimed at the establishment of both protected areas in Abruzzo region and the system of European Apennine Parks (APE). He has been a strong supporter of biodiversity conservation, and he made the knowledge of ecosystem dynamics a key point of his courses at university.

Prof. Romano has been a national reference for land take dynamics inspiring research and studies by many research groups. He always has been strongly convinced that land and urban planning plays a key role in sustainability of transformations. In fact, the dynamics of land transformation have always been a focus of his research and he has worked for years for drawing a precise and analytic description of the Italian settlement evolution. In the last period, he was active in the national discussion about drafting a law for stopping land consumption.

He has approached urban planning, ecology, and landscape both inside and outside the academic context, enriching the research with humanity. He has always been fascinated by the computational aspects of urban planning and by the possibility to explore new scientific approaches based on data analysis and indicator engineering. He has been a courageous explorer into this field, always looking for innovating the panorama of techniques and tools for spatial diagnosis.

Thanks to his creative vision, integrity, rigorous research, scientific excellence, and exceptionally broad intellectual horizons, he has left his imprint on the lives of students, PhD students, young researchers as well as many colleagues and collaborators from various institutions. He has also taught the value of autonomy of thought and collaboration.

He did so with passion, dedication, and desire to spread his great knowledge of Land Sciences.

He has left us with a significant legacy that we are going to preserve and share.

November 2023 CENTROPLANECO

Preface

The 12th International Conference on Innovation in Urban and Regional Planning (INPUT2023) has been organized by CENTROPLANECO group of DICEAA – Department of Civil, Construction-Architectural and Environmental Engineering of the University of L'Aquila.

It took place in L'Aquila (Italy) on September 6–8, 2023, and has been titled "Working for sustainable soil management and the role of land planning". Global challenges related to the sustainability of land transformations require the measurement of land transformations through specific indicators. Spatial planning and land management systems then play a crucial role in addressing issues of policy reform and investment, ecological transition, and sustainability in its three dimensions: environmental, economic, and social aspect. Integrating sustainability into our policies, strategies, and practices is fundamental to making a relevant impact with respect to current issues related to climate change, ecosystem services' provision and the energy supply.

INPUT2023 has given the opportunity to discuss such central issues and try to find and assess innovative and advanced methodologies to provide decision support systems through land science and indicator engineering.

Those proceedings represent the state of the art of modelling and computational approaches to innovations in urban and regional planning, with a transdisciplinary and borderless character to address the complexity of contemporary socio-ecological systems and following a practice-oriented and problem-solving approach.

In particular, this book presents the collection of 62 papers submitted at the INPUT 2023 Conference. The accepted papers, after a blind-review process, are here organized according to the thematic sessions of the conference:

- Resilient, Circular, and Sustainable Cities
- Integrating Ecosystem Services into Spatial Planning Processes: Sustainable Solutions for Healthier and Safer Urban and Rural Environments
- Supporting the Transition Towards Ecologically-Oriented Urban Planning: What's the Role of Early-Career Researchers? Innovative Findings, Experiences, and Ways Forward
- Towards Denser and Greener Cities? Methods and Indicators to Monitor Trends and Impacts in Support of Urban Planning and Policies
- Innovative Approaches and Methodologies for Driving Sustainable and Inclusive Urban Regeneration
- The Innovation of Urban Planning Tools for Energy-Resilient Cities
- Smart Happy Region. Relationship between Planning and Subjective Well-Being
- Climate Sensitive Planning: Re-defining Urban Environments for Sustainable Cities
- Urban and Peri-Urban Areas: Building Knowledge and Mapping to Better Plan the Sustainable Green City
- Densification and Urban Regeneration for Climate Adaptation in Sustainable Settlements.

INPUT is a scientific community of Italian university and academic researchers who meet every two years and discuss issues from different fields related to urban and regional planning topics.

The latest editions have been hosted in Viterbo (2018), Turin (2016), Cagliari (2014), Potenza (2012), Catania (2021), and L'Aquila (2023).

During INPUT 2023 (L'Aquila), the conference recorded the following numbers:

- 20 parallel sessions have been organized from experts in different fields of research related to urban and land planning.
- 171 submitted abstracts.
- 124 accepted papers.
- 130 among online and in presence participants.

Keynote Speakers of the INPUT2023 Conference

Three keynote speakers enrich the programme during three plenary sessions. Speeches have been held by:

Sara Meerow, School of Geographical Sciences and Urban Planning, Arizona State University

She is an associate professor in the School of Geographical Sciences and Urban Planning at Arizona State University where she leads the Planning for Urban Resilience Lab. She is an interdisciplinary scholar working at the intersection of urban geography and planning to tackle the challenge of making cities more resilient in the face of climate change and other social and environmental hazards, while at the same time more sustainable and just. Her current projects focus on conceptualizations of urban resilience, planning for urban resilience in a changing climate, and green infrastructure planning in a range of cities in the USA and internationally. She has published over 30 articles in academic journals, in addition to book chapters, reports, and popular press articles on these topics. She has a PhD in Natural Resources and Environment from the University of Michigan and an MS in International Development Studies from the University of Amsterdam.

Title of keynote speech: *Urban climate change resilience planning in theory and practice*

Jacques Teller, Local Environment Management and Analysis, University of Liège, Belgium

He is a professor of urban planning at the University of Liège, where he is leading the Local Environment Management and Analysis (LEMA) research group. He is a member of the Scientific Council of the Lab Research Environment (Vinci, Paritech) and of the Efficacity Research Institute in France. His research typically combines urban governance issues with the modelling of urbanization and densification dynamics. It addresses the impacts of urbanization on energy consumption, heritage management, housing provision, and transport demand. He is presently working on the interactions between urbanization and exposure to floods, combining quantitative modelling and qualitative approaches.

Title of keynote speech: *Urban growth models for regulating urban densification in response to zero net land take policies*

Claudia (van der Laag) Yamu, Department of Built Environment, Oslo Metropolitan University, Oslo, Norway

She is an architect and urban planner. She is a professor of urban analytics at Oslo Metropolitan University. She is an expert on transport land use planning including people's behaviour in cities applying a wide range of analytical techniques including method and tool development at the forefront of virtual modelling. As a former project consultant, she excels in combining the theoretical innovations with practice-oriented solutions and has been involved in numerous international projects in industry and research. Claudia was awarded the prestigious Michael Breheny Prize in 2015 for her work on multiscale, multifractal urban planning models. She is an editorial board member for Springer's The Urban Book Series. She holds a PhD in Architecture from TU Wien connecting architecture, urban planning, and computer science and a PhD in Geography and Regional Planning in complexity-based modelling from Université de Franche-Comté. She dedicates her work to the development of sustainable cities and regions.

Title of keynote speech: *Accessibility and multiscalarity: fractal urban planning models*

Best Paper Award

Among the contributions, four papers have been selected for the Best Paper awards:

1. **Giovanni Cialone Best Paper Award** addressed to studies on inner areas, protected areas, and sustainable development. The award is dedicated to the memory of Giovanni Cialone: architect, passed away in 2020. He has been a CNR researcher (National Research Council) and served in the 1990s as an environmental councillor for the municipality of L'Aquila. He was highly committed to issues related to environmental protection and education, sustainability, and cultural enhancement of inner areas. He held the position of vice-president of the Gran Sasso–Monti della Laga National Park and was a member of the "Italia Nostra" association and a delegate of Slow Food. He enriched the debate about knowledge and defence of the territory defence, with a strong presence in the media and interventions in the political sphere, consistently displaying a well-regarded balance in his positions and numerous contributions of critique.

   The award goes to the paper titled: *"The shapes of the adaptive ground design: formulation of a new taxonomy between spatial quality and ecological performance"* authored by: Simone Porfiri, University of Camerino (Italy).
2. **Giorgio Pipponzi Best Paper Award** addressed to studies on advanced GIS techniques. The award is dedicated to the memory of Giorgio Pipponzi: After his studies in geology and a PhD in geodynamics, he carried out highly professional positions in the Abruzzo Region, with the Basin Authority and the Civil Protection Service. He collaborated in the drafting of the Guidelines for the Seismic Microzoning Plans, in the development and management of computer databases as well as in the Level 3 Microzoning Pilot Project in the municipality of Sulmona. Since 2013 in the USRC, he has carried out his activity as Technical Geologist Directive Instructor, dealing with the geological problems inherent in the Reconstruction Plans and Private Reconstruction projects as well as being responsible for the GIS systems of the USRC. In 2019,

he was appointed Head of the Procedure for the technical-economic investigation of the private reconstruction projects after the 2009 earthquake.

The award goes to the paper titled: *"The applicability of the urban digital twin in the detailed choices of the urban plan"* authored by: Federica Cicalese, University of Salerno (Italy).

3. **LAND Best Paper Award** addressed to studies on urbanization phenomena, densification, and land consumption. The award intends to enhance the merit of young researchers who will present scientifically relevant papers on topics related to urbanization phenomena, densifications, and contrasting land consumption. Work should focus on the role of urban and regional planning in urban growth management with the goal to meet specific needs while increasing the resilience of urban settlements. This award refers to the special issue "Towards Sustainable Urban Development: New Approaches and Tools for Regeneration Strategies".

The award goes to the papers:

- *"Space Syntax vs Agent-Based Modelling in the maze of urban complexity: a critical comparison between top-down and bottom-up approaches and applications"* authored by: Federico Mara, University of Pisa (Italy).
- *"Urban energy resilience and strategic urban planning in Emilia-Romagna: evidence from three cities"* authored by: Giovanni Tedeschi, University of Parma (Italy).
- *"Digital Twin for urban development"* authored by: Angela Martone and Monica Buonocore, University of Sannio (Italy).

November 2023

Alessandro Marucci
Francesco Zullo
Lorena Fiorini
Lucia Saganeiti

Organization

The 12th International Conference on Innovation in Urban and Regional Planning (INPUT2023) was organized by the CENTROPLANECO group of the DICEAA-Department of Civil, Building, Architectural and Environmental Engineering of the University of L'Aquila. The composition of the organizing groups is shown in detail below.

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Towards Denser and Greener Cities? Methods and Indicators to Monitor Trends And Impacts in Support of Urban Planning and Policies

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The energy Transition of the Built Environment

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Urban and Peri-Urban Areas: Building Knowledge and Mapping to Better Plan the Sustainable Green City

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Densification and Urban Regeneration for Climate Adaptation in Sustainable Settlements

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- Institute for Environmental Protection and Research-ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale)
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Densification and Urban Regeneration for Climate Adaptation in Sustainable Settlements

Energy-Saving and Urban Planning: An Application of Integrated Spatial and Statistical Analyses to Naples

Gerardo Carpentieri, Carmela Gargiulo, Carmen Guida(✉), and Floriana Zucaro

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Abstract. The worldwide push to promote sustainability has placed the energy transition as an action priority, especially considering the impacts of climate change and the current energy crisis. Despite the widespread acceptance that local action is essential for achieving low-carbon cities that save non-renewable energy sources, a lack of integration between energy-saving solutions and urban planning continues to hinder the work of local decision-makers, technicians, and practitioners. This study integrates statistics and spatial analysis techniques to investigate the relationships between urban characteristics and residential energy consumption. The study is a first step of wider research which employs a GIS-based methodology on an urban scale to support decision-makers in identifying the most effective urban areas and fields of intervention to reduce urban energy footprint in the face of climate challenges and emerging geopolitical scenarios related to energy supply. The spatial and statistical analysis was based on variables related to key urban characteristics, including socio-economic, physical, functional, and environmental factors. The research was conducted in the city of Naples, Italy, and the results indicate that the GWR methodology differently explains residential energy consumption values according to the urban context. The outcomes support local decision-makers defining a knowledge frame of urban context in order to identify energy saving interventions.

Keywords: Urban Planning · Energy Sustainability · Spatial Analysis

1 Introduction

Urban scientists, stakeholders, and planners are greatly concerned about energy consumption in urban areas. The activities taking place in urban areas are responsible for approximately 75% of the world's total energy consumption and 50–60% of its greenhouse gas emissions [1]. Although cities are recognised as major contributors to environmental problems, they also have a critical role to play in addressing global challenges like climate change and the energy crisis triggered by the Russian-Ukrainian conflict. With extensive urbanisation worldwide [2], it is worth delving into the energy footprint of the urban environment for sustainable socio-economic development.

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Only recently, urban energy planning has been drawn to the attention of city planning. This delay has led, in the past decades, to a lack of coordinated strategies for balancing urban and energy-related development and efficient implementing policies for energy saving. To enhance energy planning, it is crucial to incorporate it within the iterative urban and territorial transformations cycle, described in the following figure (Fig. 1).

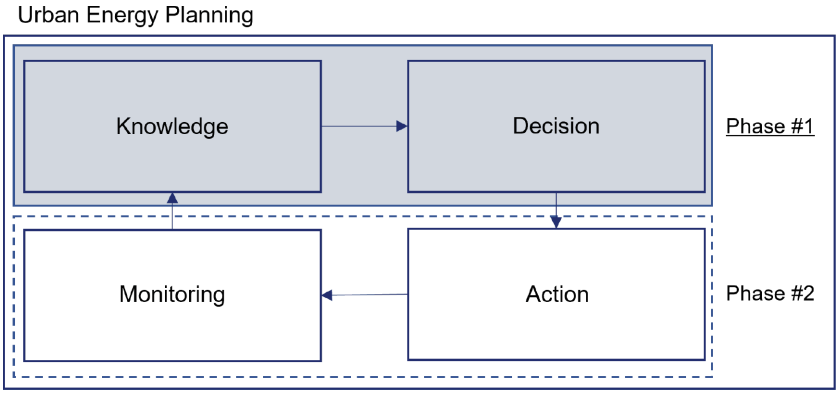


Fig. 1. The iterative urban and territorial transformation cycle for energy efficiency and saving-oriented planning.

The cycle allows the management of the urban system as a whole and its development towards future and compatible states, to face potential challenges. This approach involves four steps organized into two main phases: Knowledge, Decision, for the first, and Action and Monitoring, in the second phase [3]. The first phase plays an essential role in the whole process since it involves the analyses and interpretation of the urban context (Knowledge) to support decision-makers in defining a set of interventions (Decision) to improve the energy saving performance of a city. The second phase aims at gradually implementing the set of chosen interventions, also according to the available resources (Action) and assess the performance of developing scenarios (Monitoring), eventually adjusting the planning path (in that case the iterative cycle may start again). Hence, the starting point to enhance energy planning is deepening the relationships among economic, environmental and urban features and energy consumption.

In the last decades, scientific communities have been developing models to investigate, simulate and predict energy consumption at the urban level. Two categories can be identified: top-down and bottom-up models [4–6]. When analysing cities, top-down models take a macroscopic view, and they do not focus on punctual energy usage but rather treat the built environment as a whole and use historical energy data to understand energy consumption. These models account for the evolutionary effects of urban phenomena on energy consumption (e.g. technology, socioeconomics, etc.). On the other hand, bottom-up models examine energy use at the microscale of individual buildings and extrapolate the data to larger regions. This approach relies on extensive data to analyse the energy consumption of each user.

Despite extensive research on urban energy, most studies have failed to adopt a holistic approach that integrates energy and land use planning. Only recently, a few models have been created to address the limitations of a sectorial approach. Cityish [7], SEMANCO [8], and Urban SEM [9, 10] are representative examples of these tools. Thus, examples like these are still rare in the European context and they hardly ever find an application into urban planning practice.

The main objective of the initial research is to support local decision-makers, in the first phase of urban energy planning cycle, to support decision step, identifying key urban areas that require intervention to reduce energy consumption. In particular, this contribution presents a first step of this wider research, presenting the results of an innovative hybrid methodology to understand the significance level of urban features affecting energy consumption to support the decision-making process. The methodology has been designed to be fully managed in GIS (Geographical Information System) environment: GIS tools can effectively combine statistical and mathematical aspects of both bottom-up and top-down models due to their flexibility and interpretation capabilities.

The work describes the case study of Naples, Italy, where statistical and spatial statistical analyses techniques were jointly applied to investigate the relationship between residential energy consumption with the physical, functional and socio-economic features.

This paper is divided into different sections. After this introduction, the second section discusses the methodology used, while the third section presents the results obtained for the study area, the City of Naples. Finally, the last section contains the main conclusions of the contribution and future developments of the overall research.

2 Materials and Method

In this contribution, we opted to test a GIS-based hybrid (top-down and bottom-up) methodology, to be integrated into urban planning decision processes, based on open-source data concerning urban features and residential energy consumption. Figure 2 below summarises the methodology workflow.

Different methods have been employed to capture energy-consuming urban areas, as summerised in the previous paragraph. Thus, only a few of them has adopted a holistic approach and has been designed to effectively support decision-making processes.

This study employes an array of GIS-based statistical analyses to interpret which urban features significantly affect urban energy usage and where dependencies among variable are more significant. Hence, the results may explain where these relationships are useful for decision-makers in energy planning. Since the methodology has been designed to support effective energy saving-oriented urban planning practice, data were collected using opensource dataset.

To begin, we identified the urban characteristics and corresponding variables that have the greatest impact on energy consumption. Our selection was based on previous research by [11–16]. For this application, we chose 23 variables among the most representative of the whole urban system and its interactions. They are grouped according to the urban subsystem they relate to:

- Residential energy consumption given as kWh consumed annually by urban reidents;
- Physical characteristics. Information such as the number of buildings, their age and condition, construction type, number of floors, and surface area, is important to understand the key features of the urban fabric and built environment;
- Socio-economic condition. The social and economic circumstances of a city may have an impact on energy usage. Therefore, we have chosen to collect data on variables such as the number of residents, average age, age demographics and employment status. Additionally, variables detecting the intensity and frequency of urban activities have been collected, such as the main land use destinations and the number of employees per each census tract.

We will enrich the list of chosen urban components and related variables, in developing further steps of the research, by performing an extensive systematic literature review and through surveys and focus groups with experts and decision-makers.

The main sources of data are Municipality [17], ISTAT [18], Urban Atlas [19]. Once all data were collected, they were associated with census tracts, which are the minimum territorial reference area for this study and standardised according to min-max scaling technique. The output of this first phase is a set of arrays, for each territorial unit, collecting standardised data about dependent variable y (energy consumption) and independent variable x_i (concerning urban features).

The second step concerns statistical and spatial analyses to obtain a model defining the strength (magnitude of closeness) and the kind (positive or negative) relationships between the dependent variable and independent variables. In this phase, an exploratory regression analysis was firstly performed to evaluate all possible combinations of the input candidate independent variables that best explain the dependent variable within the context. The spatial autocorrelation analysis is at the basis of this step. Using the Global Moran's I Statistics and given a set of features and an associated attribute, this tool calculates a z-score and p-value to indicate whether the null hypotheses can be rejected. In this case, the null hypothesis states that the values of the features are spatially uncorrelated. Secondly, we performed separately two models: the ordinary least squares regression (OLS) and the geographically weighted regression (GWR).

The degree of correlation between variables is a crucial factor to consider before conducting the two spatial analyses, to avoid data redundance and multi-collinearity. To choose the best set of variables with a low level of multi-collinearity, it is necessary to execute an exploratory regression analysis. Following the exploratory regression analysis and choosing the best set of variables, spatial statistical analyses were run to determine the relationships between urban characteristics and energy consumption. The best viable set obtained is analysed by applying OLS and GWR regressions. The regression models (GWR and OLS) with selected variables allows for an interpretation of the spatial dynamics of energy consumption by highlighting spatial dependency, nonstationary and correction. It is especially useful for identifying the spatial distribution of relations between the energy consumption and selected variables.

The GWR differs from traditional Ordinary Least Squares (OLS) regression in that it estimates a specific regression equation for each territorial unit using a weighted distance matrix. The matrix assigns weights and significance levels to spatial units based on their proximity to an observation point, overcoming the assumption of equal weights in the

OLS model. The result of the second phase of the proposed methodology is an array of coefficients labeled as $\beta_{i,k}$. The subscript *i* pertains to the selected variable, while *k* to the territorial unit. Hence, the methodology would allow to produce k models that highlight which variables are more significant to explain energy consumption and how these dependencies differ within a territory. The case-study approach was adopted to capture the complexities of the phenomenon and gain a detailed understanding of the potential applicability of the methodology. Naples, in Southern Italy, has been chosen as test case and its details are described in the following paragraph.

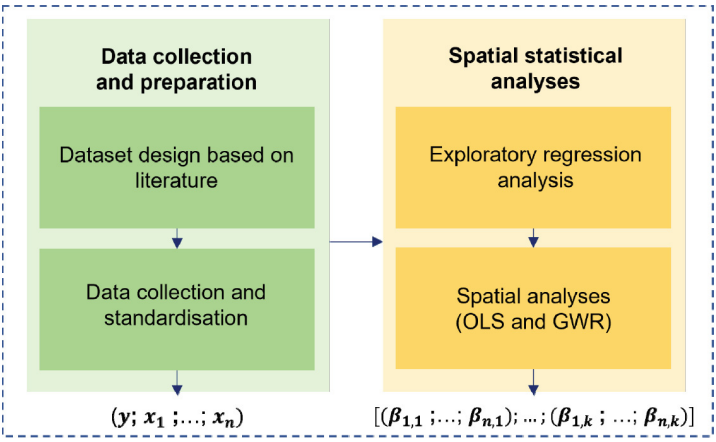


Fig. 2. Methodology workflow.

3 Results

Naples, the third largest city in Italy, has a population of 959,188 [20] and a population density of 8,059 inh./km^2 (ISTAT, 2020) over an area of 119.02 km^2. The city is divided into twelve neighbourhoods and ten borough authorities, each with different physical and functional characteristics (Fig. 3).

Naples can be considered as a representative coastal city in the south-eastern Mediterranean region. The city is a historically significant city known for its rich cultural heritage and diverse urban fabrics. From the city centre to the inner city, Naples showcases a complex blend of architectural styles, urban layouts, and historical layers that have evolved over centuries.

The historical centre is characterised by a Hippodomeo orthogonal layout, given the city Greek origins. The urban fabric here consists of narrow streets that follow the contours of the hilly terrain. The buildings typically exhibit a mix of architectural styles and construction types. Moving to the inner cities, the urban fabric gradually transforms itself to a more diverse and contemporary landscape. While historic buildings still exist, modern constructions, including residential complexes, commercial developments, and industrial settlements (both functioning and dismissed) become more prevalent.

Naples has been chosen as case-study because, due to its heterogeneities, the results may provide insightful elements to test the methodology in a complex and stratified urban environment, and further develop it.

Fig. 3. The city of Naples and districts boundaries.

The first step of the proposed methodology provided a set of significant variables that we collected using opensource data. The list of 23 variables was the starting point for applying the methodology to the selected case study. The result of the first step is an array of standardised variables, both dependent (energy consumption) and independent (physical, functional and socio-economic variables).

Secondly, a GIS-based exploratory regression analysis was performed to highlight which independent variables, within the list, were more significant to explain the dependent variable. The performed spatial autocorrelation analysis shortened the initial list to five significant independent variables to perform further statistical analyses. Four of them depict the physical characteristics of Naples, namely the average building period (P01), the average state of conservation of buildings (P03), the number of buildings (P05) and the extension of green urban areas (P06), per census tract. The socio-economic dimension is depicted only by the number of population (S01).

Spatial statistical analyses, OLS and GWR, were performed on the most significant set of variables to built up an explaining model of energy consumption. Different criteria were used to compare the performance of GWR and OLS. In this study, Multiple R-Squared (R2) and Akaike Information Criterion (AIC) criteria were used for evaluating the efficiency of GWR (Table 1). Globally, the results showed that the values of R2 and AIC for GWR are 0.43 and -8,018.6, respectively. These results show the good accuracy of GWR in preparing the urban energy model, based on the employed variables. Exploratory regression and GWR combined analysis allowed to identify the most

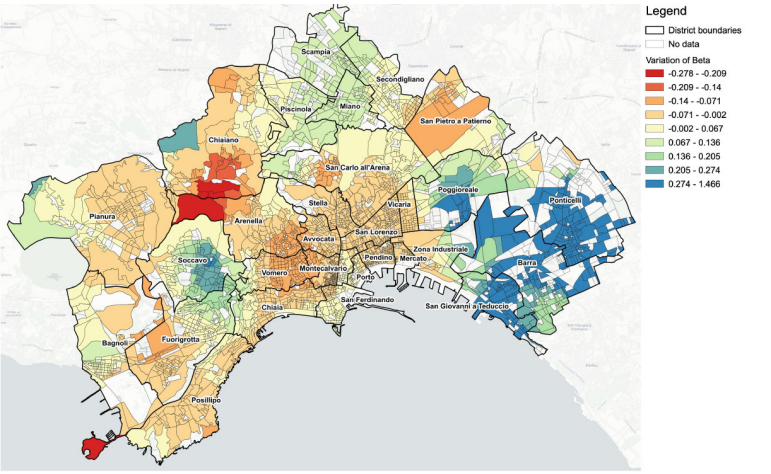
suitable model to explain the relationships between urban characteristics and energy consumption. Hence, a geographically weighted regression model was built to explain the dependent variable through the independent ones. After generating the model's β coefficients, we created thematic maps to display the direct and indirect proportional relationship between the independent variables and energy consumption, along with the extent of the correlation.

Table 1. Statistical outcomes

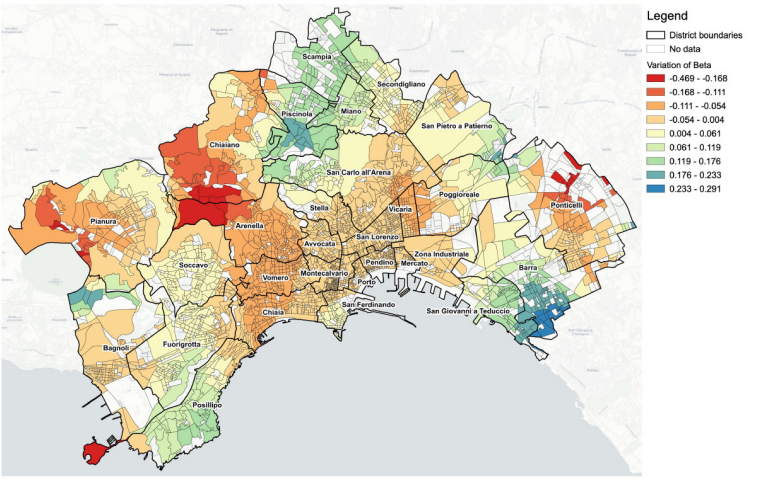
	OLS	GWR
Multiple R-Squared (R2)	0,3516	0,4282
Akaike Information Criterion (AIC)	−8780,270	−8018,581

Figure 4 shows the classification of census tracts according to the β variation ranges for each one of the GWR model variables. P01 and P03 (Fig. 4a and 4b) show similar relationships with energy consumption: negative in the central historical districts like Avvocata, Montecalvario, Vomero and San Lorenzo, that are representative of the building and urban stratification characterising the city of Naples, and in the northern suburb of Chiaiano where its naturalistic-agricultural connotation has been weakened by the development of spontaneous settlements resulting from "aggressive" building speculation. Positive values mark Scampia, Piscinola and Miano districts in the northern peripherical crown where high building densities and the detriment of the provision of public spaces and collective services are the common urban features of these districts. Census tracts between Chiaiano and Arenella have strong negative values for both these variables. Finally, it is worth noting that the variation of P01 is well defined, as the β values are strongly positive, in the eastern area of the city (Barra, Ponticelli, San Giovanni a Teduccio and part of Poggioreale) which has the characteristics of an industrial urban periphery characterised by a notable level of functional promiscuity and degradation. in fact, here production activities are flanked by large technological plants (purification plants, power stations, etc.), railway, motorway and airport infrastructures.

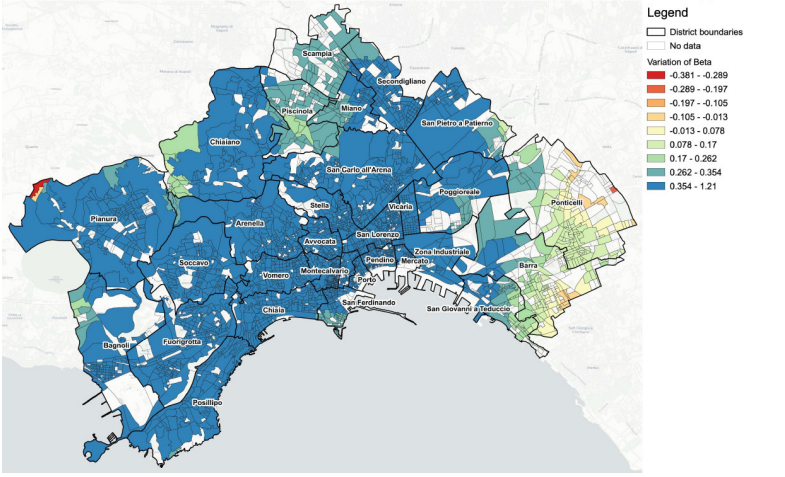
P05 is characterised by a relationship that differs completely from the other physical variables, as its relationship with energy consumption is strongly positive in almost the entire urban area. In fact, it is clear from Fig. 4c that the variation of β has a unique positive behaviour from the western part, subject to intense urban transformation and redevelopment processes (e.g. Bagnoli district) to the eastern one to be reconfigured by bringing it closer to the rest of the city. Positive but lower values characterise the northern suburbs of Scampia and Piscinola. Moving from the building variables to the one related to the urban context (P06), it is possible to identify two macro-areas in the municipal territory: the western area with the intense and not always controlled building process in the districts of Pianura and Soccavo and the sparsely built-up, low-density area of Posillipo are characterised by positive relations between the presence of green areas and energy consumption, while the area extending from the hilly district of Arenella to the eastern borders of Barra and Ponticelli where this relationship takes on values close to zero. Exceptions are the Bagnoli and Fuorigrotta districts and part of the Barra



(a) - P01

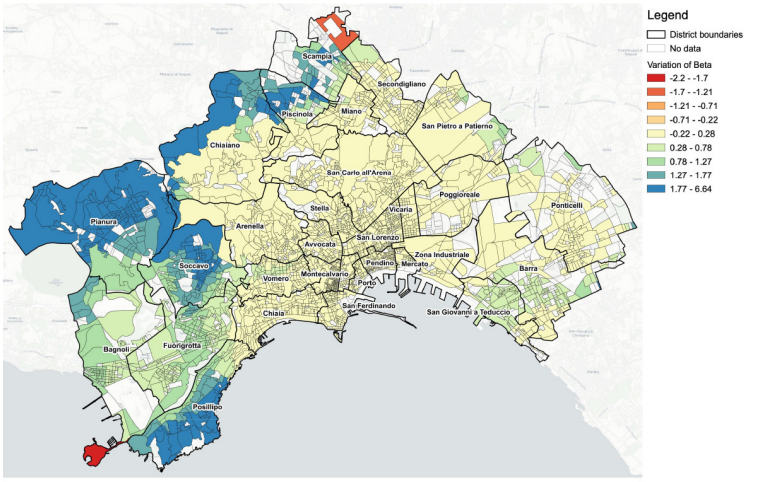


(b) - P03

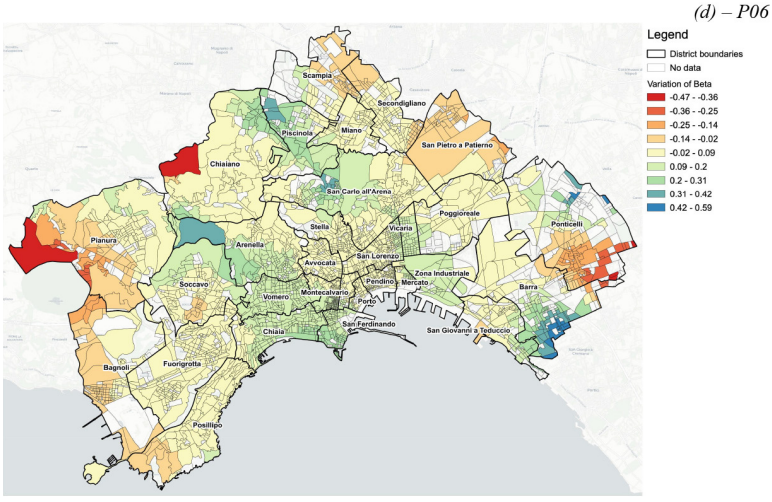


(c) – P05

Fig. 4. Regression coefficients.



(d) – P06



(e) – S01

Fig. 4. (*continued*)

district, respectively, characterised by positive values. Finally, regarding the only socio-economic variable in the GWR model, there does not seem to be a prevailing bias in the distribution of β values, as seen in Fig. 4e. Values close to zero are prevalent in the urban area, especially in suburbs such as Fuorigrotta, Chiaiano and Miano and the central ones of Stella and Pendino; the hilly area stretching from Arenella to Chiaia seems to be the only 'homogeneous' part of the territory with positive values.

4 Conclusions

The current energy crisis is throwing new light on the energy transition issue, which is now a first-order topic on urban planning agendas worldwide. On one hand, the effects of non-renewable energy sources on the global climate (in terms of GHG emissions) and, on the other, the increasing urbanisation help make the energy issue even more urgent. Within this scenario, cities have been affirmed as key actors in the hoped-for transition. In reviewing the literature, very little was found on energy planning at the urban scale, not only in assessment methodologies but also in terms of applicability to real-world urban planning practice. While some urban planning tools have been introduced to mitigate the use of non-renewable energy sources and, generally, improve the energy efficiency of urban areas – e.g. Piano di Azione per l' Energia Sostenibile e il Clima (PAESC) – effective tools to support decision-makers to define the most suitable interventions and monitor their performance over time are still missing. This contribution shows the first results of wider research aimed at improving the energy urban planning process by designing a GIS-based methodology to identify which urban characteristics impact residential energy consumption most and where these relationships are the strongest by applying an spatial statistical analyses techniques. The methodology design has been applied to a case study for validation and enhancement for further advancements. Naples, Italy, has been selected as a representative case study for the urban areas of the Southern Euro-Mediterranean region. First, the explorative regression analysis was conducted to reduce the set of 23 variables selected by the literature review. This phase revealed that five variables have a low multicollinearity value. Hence, these are the most representative and significant to create the Knowledge frame and depict the intensity and spatial distribution of relationships between urban characteristics and residential energy consumption. For this application, the selected variables are the quality and age of the building stock and the extent of green areas, and the number of residents. The geographically weighted regression further investigates these relationships. The maps presented in the previous paragraph, concerning the distribution of β coefficients highlight where physical and socio-economic features are more related with the energy consumption. This initial exploratory result serves as a valuable tool for understanding the potential of this methodology and its possible applications in energy planning process. By clustering β coefficients, it becomes easier to understand energy consumption in relation to the urban areas where it occurs. However, it is worth noting that this research has a few limits, related to energy and census data. In fact, using census data from 2011 could lead to interpretive doubts due to differences between the current city scenario and the data from 2011. Moreover, this contribution only took into account electric residential energy consumption data, due to the unavailability of more detailed data, such as a breakdown of energy consumption based on the different sources of energy. Further, the list of chosen urban components and related variables may be further enhanced by an extensive systematic literature review and through surveys and focus groups with experts and decision-makers. The highlighted limits will guide the future developments of the research in order to provide and effective and applicable tool to support decision-makers in energy and urban planning practice. In particular, we aim at developing an informative expert system able to suggest a set of effective energy saving interventions and prioritise their implementation in order to optimise the related advantages.

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