Micro renewables in residential development

An integrated GIS-based multicriteria planning approach for decentralized micro renewable energy production in new settlement development under Italian planning conditions. A case study of the eastern metropolitan area of Cagliari, Sardinia, Italy.

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Abstract

In recent years there has been increasing interest in using alternative and renewable energy sources to heat or power homes. Micro-renewable generation involves energy production on a small scale (i.e. via wind, solar, biomass and geothermal sources) to supply low-consumption buildings. It can help ensure security of supply and promote sustainable development. However, knowledge regarding its integration into housing developments in order to optimize energy efficiency, environmental concerns and other criteria for new settlements, remains limited.

This thesis illustrates an approach for the integration of micro-renewable technologies into the planning of new housing developments, according to principles of sustainability. The underlying requirements were that not only the energy potential of the landscape should be taken into account, but also the environmental concerns and preferences of (urban/spatial) planners as to settlement locations. Spatial variations in energy potential were evaluated by adapting existing methods identified in literature and expert interviews, in addition to testing the methodology using GIS data for study areas in Italy and Germany. This resulted in maps showing the energy potential for each renewable resource.

General (not spatially explicit) preferences of planners, regarding the location and planning of housing developments with micro-renewables, were identified through a survey of over 100 respondents. This survey involved pairwise comparisons of relevant factors, which were then translated, using the Analytical Hierarchy Process, into relative weights. Subsequently, these weights were applied to factor maps in GIS software, via a weighted linear combination method, to generate spatially explicit outputs for the eastern metropolitan area of Cagliari, Sardinia. One such map represented suitable areas for new settlements, and another, the preferred locations for micro-renewable technologies. These maps were then overlaid with the technical assessment of energy potential to identify areas with the highest integrated suitability for new energy efficient settlements. Such sets of maps can support decision-making regarding sustainable, energy efficient housing development. They may also indicate areas with conflicting demands, in addition to sites with specialized qualities, or those with the highest synergy potential.

The study showed that the eastern metropolitan area of Cagliari has a very high potential for the installation of micro-renewable power plants. The method proposed can be an effective tool for planners to simulate new residential areas by evaluating energy potential to track changes, in order to determine the best solution. According to expert preferences, a number of alternatives for future housing development were identified, which can be integrated at the beginning of the planning process in land use plans, or development plans.

Keywords: micro-renewable energy potentials; multicriteria analysis; residential development; Analytical Hierarchy Process.

Zusammenfassung

Die Nutzung von alternativen und erneuerbarer Energiequellen für die Strom- und Wärmeerzeugung hat seit einigen Jahren eine hohe Bedeutung erlangt. Speziell die Mikroenergieerzeugung (z.B. über Wind, Sonne, Biomasse und Geothermie) dient in diesem Zusammenhang der energieeffizienten Ausrüstung von Gebäuden. Einerseits können solche Technologien dazu beitragen, Versorgungssicherheit zu gewährleisten und eine nachhaltige Entwicklung zu fördern. Anderseits fehlt noch das Wissen, wie man Mikrotechnologien am besten in Siedlungen integrieren kann, um die Energieeffizienz zu optimieren und gleichzeitig andere Umweltbelange und siedlungsplanerische Kriterien zu berücksichtigen. Die vorgelegte Arbeit zeigt einen Ansatz für die Integration von Mikrotechnologien aus erneuerbare Energien in die Planung von Neubaugebieten unter Nachhaltigkeitsgesichtspunkten auf. Zugrunde liegende Anforderungen waren nicht nur die Berücksichtigung des Energiepotenziales und Umweltbelangen, sondern auch die Beachtung der Präferenzen von (Stadt-, Raum-) Planer für die Identifizierung neuer Siedlungsstandorte.

Räumliche Unterschiede der Energiepotenziale wurden durch die Anpassung bestehender Methoden identifiziert. Als Grundlage dafür dienten Literaturanalysen und Experteninterviews sowie eine Sichtung verfügbarer Grundlagendaten. Die Methodik wurde auf Flächen in Italien und Deutschland mit Hilfe von GIS-Daten angewendet. Dies führte zur Entwicklung von Karten, die das Energiepotenzial für jede erneuerbare Ressource zeigen. Allgemeine (nicht räumlich explizite) Präferenzen der Planer zu Standort und Planung von Wohnsiedlungen mit Mikrotechnologien wurden durch eine Befragung von über 100 Teilnehmern ermittelt. Diese Umfrage verwendete paarweise Vergleiche der relevanten Faktoren, die dann durch die Analytical Hierarchy Process in relative Gewichtungen umgewandelt wurden. Anschließend wurden diese Gewichtungen in Faktorkarten eingesetzt, um mittels einer GIS-Analyse raumkonkrete Ergebnisse über eine gewichtete Linearkombination am Beispiel des östlichen Stadtgebiets von Cagliari, Sardinien zu generieren. Eine Karte zeigt die geeigneten Flächen für neue Siedlungen und eine zweite der bevorzugten Standorte für erneuerbare Mikrotechnologien. Diese Karten wurden mit der technischen Bewertung der Energiepotenzialen überlagert um Gebiete mit der höchsten integrierten Eignung für neue energieeffiziente Siedlungen zu identifizieren. Solche Sätze von Karten können Entscheidungsfindung über nachhaltige energieeffiziente Siedlungsentwicklung unterstützen und sie zeigen Bereiche mit widersprüchlichen Anforderungen, sowie Standorte mit spezialisierten Eigenschaften oder diejenige mit dem höchsten Synergiepotenzial.

Im Ergebnis zeigte sich für das Fallbeispiel, dass das östliche Stadtgebiet von Cagliari ein sehr hohes Potenzial für die Installation von Mikro regenerativen Kraftwerken hat. Die vorgeschlagene Methode kann als wirksames Instrument für Planer zur Simulierung von neuen Wohngebieten bei der Bewertung von Energiepotenzialen dienen, um Änderungen zu verfolgen und die beste Lösung zu erreichen. Die Expertenpräferenzen lassen viele Alternativen für zukünftige Siedlungsentwicklung erkennen, die ausreichend Spielraum für die Optimierung auch unter Energieeffizienzgesichtpunkten in Siedlungsplanungsprozesses von Entwicklungs- oder Flächennutzungsplänen integriert werden können.

Schlagwörter: mikro erneuerbare Energiepotentiale; Multikriterielle Analyse; Siedlungsentwicklung; Analytical Hierarchy Process.

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1. Background

More than half of the world's population of 3.8 billion people lives in urban areas today (U.S. CENSUS BUREAU 2010, www). By 2030, this is expected to rise to almost 60%, leading to rapid urbanization. Urban populations affect the environment through the high consumption of food, energy, water, and land. The building sector represents about 25-40% of final energy demand (WBCSD 2010a, www). In addition, 40% of the world's energy demand is needed for buildings in developed countries, 33% of which is utilized in commercial buildings and 67% in residential. Furthermore, worldwide energy consumption for buildings is expected to grow 45% from 2002 to 2025 (ibid.). This sector is therefore a major source of greenhouse-gas emissions, making energy savings in this field a key element of European climate change strategy.

Consequently, the sustainable future of cities depends significantly on the planning of urban growth in a sustainable way. In this context, maximizing energy efficiency of new housing developments, in combination with the minimization of environmental impacts, is a key objective. In Europe, this goal is supported by the EU's energy policy target of achieving a 20% reduction in carbon emissions, 20% improvement in energy efficiency and sourcing 20% of our energy consumption from renewable sources by 2020. The EU policy aims at the application of minimum standards of energy efficiency to buildings in every country in the EU; the creation of a certificate to inform buyers or tenants of the energy performance of the building they expect to occupy; in large, frequented, public buildings and of energy performance certificates for information (EU 2010b, www). According to the European Directive 2002/91/EC on the Energy Performance of Buildings national governments are required to implement a respective legal framework in order to improve the energy performance of buildings. Constructing buildings that do not use energy from power grids will require a combination of onsite power generation and ultra-efficient building materials and equipment.

Europe has put in place legislation to integrate renewable energies, but it is now faced with the challenge of integrating increasing amounts of intermittent power sources such as wind, solar, biomass and geothermal energies, into the electricity grid. Furthermore, to achieve the goals of EU directives, every country is obliged to develop grid infrastructure, intelligent networks and storage facilities in order to secure the operation of the electricity system. Renewable energy generation is typically characterized by intermittency, therefore it is the imperative that a mix of sources be selected and used, in conjunction with energy storage mechanisms, to best utilize the renewable energy resource and ensure a continuity of energy supply (MACLEOD: 2007, 1804). For that reason, the installation and utilization, at a large scale, of renewable resources presupposes relevant changes of all sectors of energy use, legislative and organizational modifications and, in most cases, significant investment.

Distributed micro renewable generation can be defined as *the process of alternative energy production on a small scale to supply the energy demand of low-consumption buildings, such as domestic dwellings, with the objective of reducing the direct consumption of fossil fuels such as coal, oil or gas* (PEHNT ET AL.: 2005). In its Energy Act 2004, the UK Government defines micro-generation as generation of a capacity of less than 50 kW. Put in perspective, the peak demand for a house in the winter is around 20kW. National Italian Law N. 239/2004 art.85 defines micro-generation as a production and energy transportation system based on the integration of micro generators with a total power generation of less than 1 MW, using renewable power sources, into the electricity grid. This technology has many advantages: high energy efficiency, reliability, safety, blackout prevention and mitigation, low environmental impact and low noise levels (BEITH ET AL. 2004, 3). Electricity supply is more reliable, with fewer problems passed on to the consumer as voltage is more constant. Moreover, micro-generation helps in furnishing electricity in remote areas and building micro-generators in close proximity to the consumer, helps in containing the costs of capacity and transportation (ibid.).

Smart grids, also called intelligent grids, may be the key for reducing peaks in electricity demand at the local level in order to increase the capacity to host renewable and distributed electricity sources. According to the European Technology Platform, smart grids are defined as *electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies* (EUROPEAN TECHNOLOGY PLATFORM 2010,www). Smart grids are expected to transform today's power distribution systems from centralized energy production and one-way transmission to flexible, interactive, bidirectional and efficient distribution systems (NIST 2010, www). The household, originally conceived as passive in receiving energy, is now expected to become active in producing energy itself. The energy produced should be varied, reacting to demand (cf. BEER 2009).

This situation leads to the need of new planning approaches which integrate the objectives of sustainable housing development, energy efficiency, and decentralized energy generation. In order to cope with this complex task, methodological approaches are needed which enable planners to find the most suitable and sustainable areas for housing development and choose the right micro-generation energy mix for these locations. Present scientific knowledge can support this task, but is partly incomplete or has to be put into a new methodological context.

1.1 The European scenario on energy efficiency and renewable energy sources

The **Kyoto Protocol** (1997) was first introduced for signing in Kyoto, Japan in 1997 and finally came into force in 2005, after the signature of Russia. The protocol sets binding targets for the reduction of aggregate gas emissions from developed countries for the period 2008 to 2012 by at least 5%. This target was recently reasserted in Cancun in 2010. The gases include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). To be quantified, these gases are converted to *carbon dioxide equivalent emissions*. The target reductions relate to the emission levels of a chosen base year. The target base year for the first three aforementioned gases is set at 1990 levels and 1995 for the other gases. The Kyoto Protocol provides several innovative mechanisms for achieving the set reductions. One such is emissions trading, where countries that have emission units under their threshold can sell this excess capacity to countries that have exceeded their targets. Another, Clean Development Mechanism (CDM) allows countries that are over their targets to implement an emission-reduction project in developing countries. Similarly, Joint Implementation (JI) allows countries, which are over their targets, to earn emission reduction units (ERUs) from an emission-reduction, or emission removal, project in another developed country. Developed countries are required to create a national system for the estimation of CO_2 equivalent emissions by implementing an electronic database, called a national registry.

The EU **Directive 2001/77/EC**[1]**,** *on the promotion of electricity produced from renewable energy sources in the internal electricity market,* in art. 2 defines renewable energy sources as "non-fossil energy sources ("wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases"). The directive resolved to boost the adoption of a common policy for all member states and established national indicative targets in 2010 for renewable energy production from individual member states. Member states must adopt and publish a report which should identify targets for future renewable energy consumption for the following ten years and the measures which have to be met in order to achieve those targets.

[1] Repealed by Directive 2009/28/EC.

In 2002, **Directive 2002/91/EC**[2] on the energy performance of buildings introduced a general methodology for calculating the energy performance of buildings by introducing minimum standards for new and existing buildings when subject to major renovation. The Directive also established energy certification of new and existing private or public buildings. It aims at the application of minimum standards of energy efficiency to buildings in each European country by introducing an energy performance certificate to inform buyers, or tenants, of the energy efficiency of the building they expect to occupy (EU 2010b, www). According to the European Directive 2002/91/EC on the Energy Performance of Buildings, governments are required to implement a legal framework in order to improve the energy performance of buildings. Constructing buildings that do not use energy from power grids is encouraged and will require a combination of onsite power generation and extremely efficient building materials and equipment.

Two further directives, Directive 2003/87/EC (establishing a scheme for greenhouse gas emission allowance trading within the Community) and **Directive 2004/101/EC** (amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms), established *Emission Trading Scheme* (ETS), an economically viable and efficient system for the exchange of CO_2 emissions, to manage emission decrease for the period 2013-2020. For this period, member states are required to develop a National Allocation Plan, which indicates allocation of emission allowances for the period and how they are proposed to be allocated. The ETS system requires that countries monitor and annually report their CO_2 emissions, as they are obliged to return a sum of emission allowances equivalent to their CO_2 emissions in that year to the national governments. These Directives were adopted in Italy through **Legislative Decree 216/2006** and **Legislative Decree 51/2008**.

Directive 2006/32/EC (*on energy end-use efficiency and energy services*) was issued to improve efficiency, in particular that of the public sector which is required to provide a good example for investment, maintenance and other expenditure related to improving the energy efficiency of infrastructure, or other measures adopted to improve energy efficiency. For member states, the directive established the objective of achieving a minimum annual amount of energy savings of 1% and overall savings of 9% in the period 2008 — 2016.

[2] Repealed by Directive 2010/31/EC

The **20-20-20 Climate and Energy Packet,** adopted in **2008** in Italy , aims to reduce greenhouse gases by a 20% reduction in carbon emissions, 20% improvement in energy efficiency and by producing 20% of energy consumption from renewable resources by 2020.

Directive 2009/28/EC, on the promotion of the use of energy from renewable sources, amended and subsequently repealed Directives 2001/77/EC and 2003/30/EC and established a common framework for the promotion of renewable energy resources. The directive aimed at achieving a 20% share of energy from renewable resources in EU energy consumption, and a 10% share of energy from renewable resources in each member country's transport energy consumption, by 2020. In order to achieve these objectives, the directive introduced mandatory national targets for the overall share of energy from renewable resources in gross final energy consumption for each member state, for the first time. The main purpose of mandatory national targets was to encourage technological development allowing energy production from all types of renewable resources (EU 2010b, www). To achieve the targets, each EU Member State was required to adopt a national renewable energy action plan which indicates national targets for the allocation of renewable resources. Member States are able to develop support schemes or measures of cooperation with other member states and with developing countries.

Directive 2010/31/EC, *on the energy performance of buildings*, repealed Directive 2002/91/EC and promoted energy performance improvements, taking into account outdoor and indoor climate requirements and local conditions. The Directive set down a common general framework for a methodology to calculate the integrated energy performance of buildings and for the application of minimum requirements to the energy performance of new and existing buildings subject to major renovation. In keeping with the Directive, national plans should increase the number of near zero-energy buildings; from 1 January 2019, all new public buildings, 1 January 2021 for all private buildings, will have to be energy- neutral.

1.2 Italian legislation on energy efficiency and the building sector

In Italy, legislation has focused primarily on the energy performance and certification of buildings, and on the integration of renewable energy systems.

To increase the use of renewable energies, **Legislative Decree 387/2003** (adopting EU Directive 2001/77/EC) was introduced. The Decree established a unique procedure in the issue of authorizations for buildings, putting Regions in charge of all relevant activities and procedures.

The **reform of Section 5 of the Constitution in** 2003 **introduced** the delegation of legislative powers to Regions to manage energy generation and distribution over the regional territories.

The **Legislative Decree 192/2005** adopting the above-mentioned EU Directive 2002/91/EC, established that newly constructed buildings should provide for the installation of new heating systems and set the minimum requirement that 50% of the overall quantity of hot water produced comes from renewable energy sources (e.g. solar power and biomasses). In particular, the Decree introduced energy performance and transmittance values inspections in order to isolate the houses.

A further **Legislative Decree 311/2006,** which partly modified Legislative Decree 192/2005, regulated certifications of energy performance of buildings by developing a methodology for the computation of energy performance. The Decree envisaged mandatory energy performance certification for existing buildings with a surface area larger than 100 m_2 from 1st July 2007, for all buildings from 1st July 2008, and for single building units from 1st July 2009.

Law 244/2007 ("Legge finanziaria 2008") established mandatory installation of 1 – 5 kW PV systems for industrial buildings with a surface area of at least 100 m^2. The implementation required municipalities to adapt their building regulations in order to introduce renewable energy technologies on this, larger, scale.

Presidential Decree 59/2009 in which EU Directive 2002/91/EC on energy efficiency in buildings was implemented, defined a computation procedure, which introduced minimum requirements of energy performance for new/existing buildings in accordance with those contained in Legislative Decree 192/2005. This decree introduced a maximum acceptable energy performance value for cooling new and renovated buildings in summer that has to be lower than the following parameters: 40 kWh/m^2/year in climate zones A and B and 30-40 kWh/m^2/year in climate zones C, D, E and F. The climate zones were classified according to the energy needs to maintain a constant temperature of 20 ° C.

Ministerial Decree 26/06/2009 provided national guidelines for the certification of buildings and building units that applies to those Regions and Autonomous Provinces which had not yet legislated for the matter. The energy performance certification lasts 10 years, after that it is automatically renovated if the energy efficiency of the building is coherent with the legislation in force. Energy performance of buildings is rated on a scale from A+ to G. The categories are depicted in the table below (table 1).

Table 1: Categories of energy performance of buildings and correspondents energy consumption according to Ministerial Decree 26/06/2009

Energy performance of buildings - Categories	**Energy consumption [kWh/m2/year]**
Ai+	< 16,25 kWh/m2/year
Ai	< 32,50 kWh/m2/year
Bi	< 48,75 kWh/m2/year
Ci	< 65,00 kWh/m2/year
Di	< 81,25 kWh/m2 year
Ei	< 113,75 kWh/m2/year
Fi	< 162,50 kWh/m2/year
Gi	>162,50 kWh/m2/year

While Regions are required to introduce laws on the energy performance of buildings, integration of micro-renewable technologies and a certification of energy efficiency, the Provinces are required to guide and coordinate Municipalities in producing guidelines, which become the basis for regulations adopted by Municipalities. Building regulations developed by Municipalities appear to be one of the key elements to guiding the change from building with high energy demand, using fossil fuels, to energy efficient buildings. In Italy, 705 Municipalities, both large and small, with an overall population of almost 19 million people, have recently modified their building regulations - 80% of these occurred over the last three years and 557 in 2009 alone. Modifications and revisions have mostly addressed energy saving measures, production from renewable sources, water conservation and recycling. In order to achieve the goals established by the Kyoto Protocol and to pursue European policies, Regions need to draft regional energy plans with reference to the National Energy Plan ("Plano Energetico Nazionale" or PEN) 1988. The Plan defines the objectives and priorities of energy policy as efficient energy consumption, minimization of environmental impacts, diversification of sources and replacing traditional energy sources with renewables.

In the following table we report in table on the European and Italian legislation (table 2).

European legislation		Italian legislation
Directive 2001/77/EC (*on the promotion of electricity produced from renewable energy sources in the internal electricity market*)	repealed by **Directive 2009/28/EC** (*on the promotion of the use of energy from renewable sources*)	**Legislative Decree 387/2003** (*on the promotion of renewable energy sources*)
Directive 2002/91/EC (*on the energy performance of buildings*)	repealed by **Directive 2010/31/EC (***on the energy performance of buildings*)	**Legislative Decree 192/2005** **Legislative Decree 311/2006** **Presidential Decree 59/2009**
		Reform Section 5 of the Constitution (2003) Transferring the legislative competences for the production and distribution of energy to the regions
Directive 2003/87/EC (*establishing a scheme for greenhouse gas emission allowance trading within the Community*)		
Directive 2004/101/EC (*amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms*)		**Legislative Decree 216/2006** **Legislative Decree 51/2008**
Directive 2006/32/EC (*on energy end-use efficiency and energy services*)		**Legislative Decree 115/2008**
		Law 244/2007 Mandatory regulations 1 kW of PV systems for each building 5 kWh for industrial buildings with a surface of at least 100 m2, implementation through building regulations
		Ministerial Decree 26/06/2009 national guidelines for the certification of buildings

Table 2: European and Italian legislation related to energy efficiency and buildings.

1.3 The planning system in Italy as a framework for the use of renewables

The basic legal instrument for regulating urban planning in Italy remains Act N. 1150 of 1942 and its subsequent amendments. Urban planning is charged with addressing landscape changes through a combined set of regulations embodied in planning instruments which are used in planning and development activities (cf. FIALE 2006).

In Italy there are two levels of planning: the urban and the regional /sub-regional levels. At the regional level, landscape planning is regulated by the Code of Cultural Heritage and Landscape, enacted in 2004 following the signing of the European Landscape Convention (ELC) in 2000. Landscape planning ensures changes are compatible with landscape values. It manages and defines landscape assets, measures on restoring buildings, developing protected areas, interventions to management and planning toward sustainable development. Under current planning legislation, landscape planning defines the guidelines of urban development compatible with the landscape values. The coordination of landscape planning with other planning tools requires the provision of landscape plans, which are binding for other planning instruments of municipalities, metropolitan cities and provinces. The provisions, set out in the landscape plans, remain compulsory in consideration with other plans. Landscape planning is of a hierarchically higher-order than urban and sectorial planning. However, the sectorial planning system means that spatial planning is influenced by specific planning issues (e.g. traffic, hydrogeological risk, energy etc.). Sectorial approaches are weighted and combined in the context of spatial planning.

However, Sardinia differs as it is an autonomous region and therefore its statute confers exclusive legislative competence in regional planning. In fact legislative competences can be conducted in full compliance with the Constitution and the regulations deriving from EU and international obligations (cf. FIALE 2006).

The region of Sardinia, by virtue of its autonomy and its special status, introduced the Regional Law L.R. 45/89 "Rules for the land use and protection of the regional territory" in 1989. This law defines the area of planning and its related tasks. It also describes the levels of Spatial Planning, the corresponding tools for the use and protection of the territory, and the relationships between different planning tools.

Information requirements of the planning instruments

The planning system can be described though a series of interrelated procedures. Plans are ordered according to a hierarchical upside-down pyramid. At the top of the pyramid, there are purely strategic instruments (planning directives) whereas the plans at the lower level (executive planning) are mandatory (cf. FIALE 2006). Normally, this hierarchy corresponds to the territorial classification (regional, provincial and municipal), in which the lower-ordered plans must comply with requirements of those of the higher-level. All plans consider the environmental and landscape protected areas. At regional level, spatial landscape plans, directives, constraints and patterns of land use are planned. At the provincial level, provincial plans are drawn up, while on the municipal level, urban land-use plans of municipalities are set out (see table 3).

Table 3: Italian planning instruments.

Planning instruments	**Contents**	**Legislative References**	**Subjects responsible for the adoption**	**Subjects responsible for the approval**	**Scale**
Landscape plan	Guidelines and regulations for the protection, management and planning of landscapes.	Legislative Decree No 24 of 2004	Region	Region	1:25.000
Territorial plan of coordination	Guidelines and coordination for the urban planning of local authorities.	National Laws No 142 of 1990 and No 1150 of 1942	Province/ Regione	Region	1:50.000 1:25.000
Inter-communal land-use plan	Regulations for urban development of the territories of several municipalities.	National Law No 1150 of 1942	Municipality/ Province Region	Region	1:5.000
Urban land-use plans	Regulations for urban development.	National Law No 1150 of 1942	Municipality	Region	1:5.000 1:4.000

The consequences of the planning system on the integration of micro renewable energy and on the choice of new settlement areas need to be considered on the regional and local scale. Guidelines and some prescriptions about the landscape are given at regional scale; however decisions are made at local level with the confluence of private interests. Therefore, a positive planning approach is needed which can be integrated with the structure of the Italian planning system and data conditions, in order to select the best sites for new settlement development with micro-renewable energies.

2. State of science

2.1 Sustainable development

In the 1987 report, "In Our Common Future - Brundtland Report", the World Commission on Environment and Development (WCDE) announced that *a low energy path is the best way towards a sustainable future,* and is considered as one of the basic elements of the definition of sustainability. Subsequently, the UN World Climate Conference in 1995, Habitat II in 1996, and the Kyoto protocol in 1997 emphasized the use of new concepts and technologies for sustainable development. According to the OECD, the effectiveness of land use planning and regulations to promote the use of renewable energy resources should be the focus for achieving sustainable development (OECD, 1995). During the preparatory meetings for the Global Conference on the Urban Future (held in Berlin in July 2000), sustainable urban development was defined as:

> *Improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden on the future generations. A burden which is the result of a reduced natural capital and an excessive local debt. Our aim is that the flow principle, that is based on an equilibrium of material and energy and also financial input/output, plays a crucial role in all future decisions upon the development of urban areas* (REC 2010, www).

The city is the result of three main interconnected forces: social, environmental and economic (CAMAGNI 1999). To achieve a sustainable city, or eco-city, new concepts for housing which strive for minimal environmental impact and the integration of several complex interrelated social, economic, political, spatial, institutional and physical factors, are needed (DROEGE 2008; RANDALL 2008). From a strategic planning perspective, urban sustainability focuses on the prospects for changes to transport and urban form for reducing energy consumption; specifically, transport management, building design, land use planning and energy efficiency. However, current city planning practice does not include an effective land-use energy evaluation in urban plans (Duvarci & Kutluca 2008). Energy concepts are not well integrated into the planning process as in the case of form, design and planning (Owens 1986; Sadownik & Jackard 2001; Means 2004). There are strong relationships between energy and planning through urban form, transport, land-use and infrastructure. With the appropriate planning and design tools, cost and pollution can be reduced. Linear urban forms and high density contribute to optimizing efficient energy use (McGeough et al. 2004; Lantzberg 2005). Low density urban sprawl implicates higher needs to travel than a more compact pattern of mixed land use and implies an increase in infrastructure costs (Owens 1989; OECD 1995).

Another important consideration is design, at urban and project scales, for energy efficiency and consumption (Jebson 1981; Fanchiotti et al. 1993; Bhatt et al. 2010). At the urban scale, energy efficiency may be maximized with urban form and transport systems (Beaumont & Keys 1982; Jones et al. 2001). Environmental impacts caused by transportation energy systems have been widely investigated (Anderson 1996; Kenworthy & Laube 1999; Holtzclaw 2002). Furthermore, applied models related to urban form, transportation and urban heating systems have been developed (Ortuzar & Willumsen 1994; Cooper et al. 2001) with some leading to the proposals of optimum urban form (Baker & Steemers 2000). However, planners still need to explore the impacts of energy-saving tools on land-use, and vice versa (cf. Bhatt & Ginsberg 2009).

2.2 Sustainable cities

There are a growing number of initiatives in EU countries which have developed sustainable approaches to both residential and non-residential buildings. Master plan works, including city-wide district heating systems, encompass energy-integrated land use planning. European cities such as Goteborg and Stockholm, Sweden; Freiburg, Germany; Aahrus, Denmark; Turin, Italy; Sutton, London, UK; and Rennes, France are models of energy efficient housing development (cf. Duvarci &

KUTLUCA 2008). In order to increase the degree of sustainable development, the aim shifts to energy-efficient design and technology, and quality of urban planning strategies (ROTMANS ET AL. 2000). In this context, there are two prominent European projects: the BedZED development in the south of London, and the Vauban development in Freiburg, Germany. These urban multi-residential housing developments are models not only for energy saving, but as they also take into account social and economical factors. Furthermore, both models achieve greater sustainability combining local public policy, planning, design and technology (cf. ENERGYCITIES 2010). While energy saving measures and energy efficiency concepts, such as better insulation or solar exposure, are only a part of the conditions for sustainable development, they are one of the most important aspects of both projects. Sustainable development is strongly connected to the interactions and relationships between social, economical and environmental processes, which are interrelated and interconnected. Although these processes differ in nature and operate at various levels, an integrated systems approach seems appropriate in analyzing the complexity of city planning (cf. ROTMANS ET AL. 2000). One example of this is open citizen participation during the planning process which can raise the acceptance of micro renewable technologies and improve their use. Considering that the planning of sustainable development is a complex issue made up of several and often different aspects, the following description and analysis of both projects focuses primarily on the integration of renewable energy in buildings, urban form and energy efficiency in urban spatial development in order to give an overview about how far energy concepts are considered and developed. Consequently, other aspects, such as transport, water, waste, local materials, social perception and participation are only briefly mentioned. Whilst environmental and social factors should be considered simultaneously as are closely related, this is not investigated in depth in the present work. However, it provides the opportunity for further research.

Beddington Zero Energy Development (BedZED)

The Beddington Zero Energy Development (**BedZED)** is the UK's largest mixed use sustainable project. It was developed by the BioRegional Development Group, in partnership with the housing association Peabody Trust, and Bill Dunster Architects in Hackbridge in Surrey (BIOREGIONAL 2010,www). BedZED was conceived to demonstrate that a high level of sustainability could be practical and cost-effective in large-scale construction (see Figure 1). The project aimed to reduce its ecological impact; both in construction and operation, and help residents live within their fair share of the local resources (ibid.). Building materials were sourced locally and heat and power for the residents is provided by renewable energy technologies.

The project comprised 82 homes and 2,500 m^2 of commercial or live/work space: 50% of the housing was offered for sale, 25% was key-worker shared ownership and 25% was designated as social housing for rent (ZEDFACTORY 2010, www). The development project, completed and occupied in 2002, was conceived with the goal of producing as much energy from renewable resources as it consumes.

The strategy for energy efficiency has included (ESUDP 2010, www):

- ✓ Reducing or eliminating space heating demand by providing a super-tight insulated shell and passive solar design.
- ✓ Providing power, heat, and hot water from a locally placed combined heat and power (CHP) plant which utilizes the wood waste from a nearby municipality.
- ✓ Installing solar power plants to provide hot water and power for electric vehicles.
- ✓ Using low energy lighting and energy efficient appliances.

The characteristic form of the buildings was linked to planning for density, combined with optimal solar exposure and daylight, fresh air, and private open space access. According to the architect *it was hard to see how higher density urban infrastructure can be achieved without stealing a neighboring plots' sunlight, or building rooms that can only be mechanically vented and artificially lit* (ibid.). Furthermore, the use of solar energy was maximized through the integration of solar cells into the vertical south-facing facades and through a large installation on the south-facing portion of the roof. Solar power plants, which cover 777 m^2, and wind turbines provide electricity and heat and add to the long list of technologies that BedZED uses, including water-saving devices and rain collectors (SUSTAINABLE CITIES 2010, www). In 2007, studies monitoring the project established that the electricity consumption of the average BedZED citizen was 45% less than that of other residents of Sutton County; heat consumption was 81% lower and the use of water was recorded as lower by 50% (IBID.).

Figure 1,2: BedZED's, United Kingdom and Vauban, Germany eco-districts (EXPO.$_{015}$, www; Solaripedia, www).

However, after a promising start, the efficiency of the combined heat and power plant (CHP) started to drop gradually from 80% of BedZED's energy produced from renewable sources in 2003, to 11% in 2006. Nevertheless, despite not attaining the goal of 'zero (fossil) energy' and with the reduction in efficiency of the CHP plant, BedZED has considerably reduced its carbon footprint (IBID.).

Germany, on the other hand, follows a mandated solar energy pricing policy which aims at starting a new generation of buildings and architectural responses. The City of Freiburg is recognized as a green city for its environmental approach and its wide use of solar energy (cf. ENERGYCITIES 2010).

Vauban, Freiburg

In the South of Freiburg, on the former area of a French barrack site, the Vauban district has been developed on 38 ha in order to host more than 5,000 inhabitants (STADTTEIL VAUBAN, FREIBURG, 2010). The whole development of Vauban was directed by the City of Freiburg. The planning for the city district begun in 1993 and the implementation phase started in 1997 (IBID.). As owner of the Vauban area, the City was in charge of its planning and development. The principle "Learning while Planning", adopted by the City, allowed flexibility in reacting to new developments as they arose (FORUM VAUBAN E.V., 2010). The main objective of the project was to develop a sustainable city district in a co-operative and participatory process in an ecological (public transport, co-generation plant, heating system, renewable energy, green areas), economical (balance of working and living areas, district shopping centre), and social and cultural (neighborhood centre for social interaction, cultural events) way (IBID.). The project's structure integrated legal, political, social and economic participants from the grassroots-level to the City administration. During the planning process the City opened an extended citizen participation process for which it also offered financial support. This allowed extended citizen participation that went beyond legal requirements and allowed citizens to actively participate in the planning process. From the start of the process, all issues (mobility, energy, housing, social aspects etc.) were discussed in working groups open to residents (STADTTEIL VAUBAN, FREIBURG, 2010). Furthermore, the citizen's association "Forum Vauban e.V." did not want to restrict itself to simply organizing forums, but became more directly involved by developing its own proposals for the planning and building of the district (IBID.). Therefore, the project was created and implemented not only by the City of Freiburg, but also with several other partners. This feature of cooperative local planning was an outstanding characteristic of the Vauban development. In the fields of energy, traffic, mobility, building and participation, social interaction and public spaces new concepts were successfully put into practice (FREIBURG CITY 2010, www). In 2007 the City Council adopted a consistent procedure, developed by the planning and environment department, which integrated energy aspects for all new development plans (IBID.) Each new development plan is required to include:

- Early consideration of energy aspects in target definition for new building areas,
- Consideration of passive solar aspects in draft plan, and
- Freiburg building standard in all new building areas.

Energy concepts were integrated through central or decentralized variant verification, CHP and the early involvement of renewable energies (see figure 2). Further details regarding the energy efficiency of the project include:

- ✓ consumption of 65 kWh/m^2/year for new buildings
- ✓ 92 passive houses with consumption of 15 kWh/m^2/year
- ✓ 10 Plusenergie Häuser "positive energy houses" which produce more energy than they need
- ✓ district heating grid and co-generation plant (wood chips: 80% and gas: 20%)
- ✓ large-scale use of solar energy with 2,500 m^2 of photovoltaic panels and 500 m^2 of solar thermal collectors

Implementation of the project was based on agreements on urban development between the City and private owners. Notably, 65% of the electricity needed in Vauban is produced on-site through CHP and photovoltaics. Low-energy housing is approximately 2% more expensive to build than traditional housing; however energy consumption falls by up to 80% compared to existing building stock and CO_2 emissions are reduced by 30% (STADTTEIL VAUBAN FREIBURG 2010). In Freiburg, the principles of energy saving and solar optimization were addressed early in the planning phase of housing development by, for example, defining the orientation and position of buildings or requiring low-energy construction requirements (cf. PASSIVEHOUSE »WOHNEN & ARBEITEN« 2010).

The suitability of micro-renewables is dependent on several factors including the availability of energy potential, building design, orientation and location. Environment-oriented eco-districts integrate sustainable design, optimize building orientation and thoughtfully plan transportation by expanding existing, or developing new, residential areas. In both of the examples provided, renewable technologies were integrated at the project scale, taking into consideration renewable energy potential according to the local characteristics (e.g. terrain and exposure) of the development areas. In both models, new housing development was located on a disused area near the city; in the case of Vauban, this area was a military area. Renewable energy is not adequately well established in current planning practice, particularly in development and land use plans, therefore the location of development is not selected from between alternatives in light of environmental criteria and micro-renewable potential. (cf. DUVARCI & KUTLUCA 2008).

In Freiburg, energy concepts, primarily taking into account solar and biomass energy, have been integrated in new development plans. In the case of Vauban, energy efficiency was increased through the introduction of passive and/or active houses (cf. PASSIVHOUSE INSTITUT 2010, www). Energy plans offer energy potential by identifying the best locations for optimizing energy sources; however they not take into account the integration of micro renewable technologies in new settlement developments (cf. BEYER ET. AL. 1997; WILLSON & GALLANT 2000). Energy efficiency should be integrated at the start of the land use planning process in order to guide future development to those sites with the best potential for utilizing renewable micro generation. Their potential can be developed in a sustainable way by using multicriteria evaluation methods in a GIS environment to help optimize new settlements in terms of multi-functionality. Thus far, there is a lack of research examining a methodological approach which can be implemented at regional/sub-regional scale to build new relationships between regional and local planning in order to guide new energy efficient settlements. Therefore, a number of unanswered questions remain: How to guide future development to the sites with the best potential for using renewable micro generation? How to plan the most efficient energy mix for new housing areas in a given region? How to take into account the environmental and landscape impacts of the development? How to optimize the settlements in terms of multi-functionality?

2.3 State of methodology development

Many urban planners propose several urban designs, based on energy consumption, without considering energy potential (LYLE, 1994; WILLIAMS & JENKS, 2000). While a large amount of research has been conducted on the technical aspects of micro generation (BROOKES 2004; ROSEN ET AL. 2005; LINDEN ET AL. 2006), the renewable energy potential at regional and sub-regional scale for micro-renewables has not been considered nor estimated (cf. DROEGE, 2007; LYLE, 1994; WILLIAMS & JENKS, 2000). Urban plans do not take into account renewable energy potential estimation for the planning of new residential areas (DROEGE, 2007). Moreover, the inappropriate location of new houses cannot wholly exploit renewable energy potential. The planning of an energy efficient residential development requires the availability of renewable energy sources for optimizing their use. The theoretical potential describes the theoretical available energy supply within a particular region in a given period. Because of existing technical, ecological, economic and social restrictions, the theoretical potential can be only exploited up to a certain percentage (RODE ET AL. 2005, STEINBACH 2002). In recent years renewable energy potential mapping methodologies were developed which can be used as a basic orientation in developing respective urban planning methods (e.g. solar irradiation and wind estimation, geothermal and biomass energy) (MAXWELL AND RENNE, 1994; IVANOV ET AL., 1996a; IVANOV ET AL., 1996b; SCHNEIDERA ET AL. 2006). However, the methodologies have been developed for very small scales and cannot be applied unmodified for selecting new housing locations (VETTORATO & ZAMBELLI 2009). For this reason, it is necessary to adapt existing methodologies or to develop new methods in case that they are missing.

State of methodologies for assessing the solar energy potential

Solar irradiation maps can be obtained by using data from solar radiometers of meteorological stations or by making direct calculations from astronomical and geographic parameters (sun declination, duration of the day and latitude). In Europe, solar irradiation is derived from 566 meteorological stations and solar data algorithms to calculate derived parameters. The mapping data is digitized into a database in the European Solar Radiation Atlas (ESRA) (HELIOCLIM 2010, WWW). Various techniques can be used to produce spatial databases from these measurements, such as interpolation techniques or data gathered from meteorological geostationary satellites (e.g. METEOSAT). In the latter case, the processing of satellite data provides less accurate values compared to ground measurements, but provides the advantage of coverage over large territories (SÚRI AND HOFIERKA, 2004). Each of these techniques could be used to produce spatial databases in the GIS environment. The Joint Research Center (JRC) of the European Commission has developed a solar radiation database from climatologic data homogenized for Europe, and available in the European Solar Radiation Atlas, which uses the *r.sun* model and interpolation techniques with 1 km resolution considering surface inclination, terrain aspect and shadowing effects. However, it is not used for housing development (see the Panel Photovoltaic GIS Program of JRC 2010b, www). The database consists of raster maps representing twelve monthly averages and one annual average of daily sums of global irradiation for horizontal surfaces and for inclined angles (15, 25, 40 degrees) (JRC 2010a, www). Considering that it is necessary to estimate the energy potential for housing development at local or sub-regional scale, more accurate data inputs are needed in order to produce more precise results.

State of methodologies for assessing the wind energy potential

Wind Energy Potential Maps can be generated from the data of meteorological stations. Wind speeds are modeled by using statistical models which take into account land parameters such as roughness, elevation, topography and ground surface cover. The wind speed distribution in Europe was obtained from 200 stations. These data sets and maps are contained in the European Wind Atlas which was published in 1989 for the Commission of the European Communities (TROEN AND PETERSEN 1989). The European Wind Atlas employed meteorological data from a selection of monitoring stations, and shows the distribution of wind speeds on a broad scale for 50 m above ground level, on shore and off shore (EUROPEAN WIND ATLAS 2010, www). Every country is required to provide accurate wind speed estimation. For instance, in Germany wind speeds at 10 m were calculated by the German Weather Service (Deutscher Wetterdienst-DWD) using the statistical wind field model (SVM), a regression model based on the work of Gerth (GERTH 1986; GERTH 1989). The spatial distribution of wind speeds was estimated using 218 series from the wind stations taking into account various factors like height above sea level, the geographic location, the relief and the land use (roughness), using a non-linear regression. In Italy, the Italian Wind Atlas ("Atlante eolico italiano") was developed in 2002 by CESI RICERCA in co-operation with the Department of Physics at the University of Genoa (BOTTA ET AL. 2007). A wind flow model (WINDS), which takes into account orography and terrain roughness, was used to obtain wind maps by validating data with measurements from 240 meteorological stations. The Atlas contains a series of 27 maps (at 1:750.000 scale) of annual average wind speeds (m/s) shown at 25, 50 and 70 m height above ground level, 27 maps depicting energy production (MWh/MW) of a hypothetical wind turbine of 50 m height, and synthesis maps (at 1:6.000.000 scale) (CASALE ET AL.2010: 17). The model was first applied to 24 different geographic areas, each 200x200 km in size. The wind data was analysed in reference to a grid of approximately 1x1 km in latitude and longitude. The accuracy of wind energy potential maps strongly depends on the wind data availability of each country. In contrast to solar energy potential estimation, it is impossible to use other data when analyzing wind potential. The data may only be derived for smaller scale analysis when considering wind speeds and relief.

State of methodologies for assessing geothermal energy potential

Geothermal energy may be divided into two categories: high-enthalpy geothermal energy for large-scale power plants and low-enthalpy geothermal energy for dwellings. High-enthalpy geothermal energy is limited to regions with high heat flow (LIEBEL ET AL. 2008, www). Low-enthalpy geothermal energy, however, can be achieved in almost any location and is derived from the soil, rocks and groundwater (ibid.). The European Geothermal Energy Council (EGEC) has developed a map showing main basins and high-enthalpy geothermal areas (EGEC 2010, www). Low-enthalpy geothermal energy needs to be investigated at a larger-scale. Several regions in both Italy and Germany have developed studies and maps for identifying the energy potential for borehole heat exchangers (vertical loops) and horizontal ground heat exchangers (horizontal loops). One such example is found in Lower Saxony, in Germany, where the energy potential for horizontal loops (at 1,2 - 1,5 m installation depth) is depicted on the potential site's suitability for geothermal heat collectors map at a 1:50.000 scale (LBEG). Not all regions have developed geothermal energy potential maps, therefore a geological map and appropriate experts should be consulted in order to estimate the ground composition and the rock stratification.

State of methodologies for assessing biomass energy potential

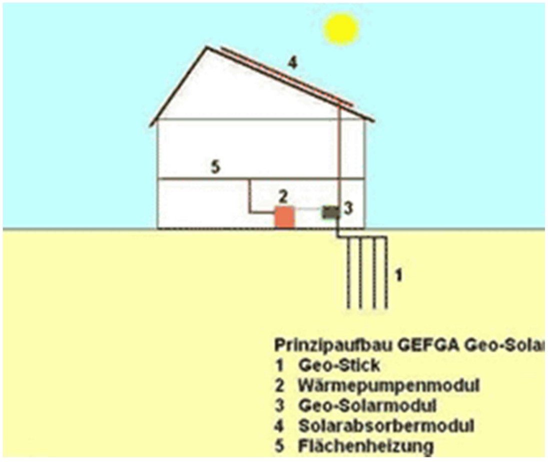
The amount of wood bioenergy available is primarily dependent on the available forest areas. Despite its high population density, around 30 % of Europe's land area is covered by forests. Biomass potential consists of forest residues. The European Environment Agency (EEA) has developed a map showing the “Suitability for residue extraction according to environmental criteria” (EEA 2006). To date, bioenergy potential has remained, for the most part, determined by market demand for wood. The European Forest Information Scenario (EFISCEN) model compiled the data from national forest inventories for projecting the possible future development of forest resources in the European Union (Karjalainen et al. 2002; Nabuurs et al. 2003; Päivinen et al. 1999). The environmentally-compatible bioenergy potential, from residues and from complementary fellings in 2030, was expressed in tOE per km^2 of land area and was determined by overlaying the suitability map and the forest map (EEA 2006). EFISCEN simulated only those forest areas that were available for wood supply. Unproductive forests and nature conservation areas were excluded. The limit to the existing methods in estimating the biomass energy potential is the lack of consideration to the distance from the forested areas to the potential new settlement.

2.4 Micro renewable energy efficiency mix combinations and potentials

The state of the art is sufficiently advanced in the field of energy efficiency of each energy sources (Brookes, 2004; Rosen et al., 2005; Linden et al., 2006), which may be increased by combining different energy sources. Structures which tackle the challenge of increasing the share of renewable energy sources in the energy mix should play an important part in sustainable settlement (MACLEOD: 2007, 1804). To date, there has been much debate concerning the multifunctional combination of different renewable energy sources, and other aspects of sustainable settlement development, in the most efficient way. It would seem that the best energy mix for new housing development can be selected by estimating the energy potential available for the whole area under consideration in order to best exploit renewable energy sources. The output variability of energy production from renewable sources may pose a restriction in securing supplies; however, this may be minimized by demand variability, especially where it correlates with times of high energy output by renewables, better predictability of their generation output and the harmonizing of different power sources (IEA, 2007). Regional variation capacity factors and variability of availability implicate that the security of renewable energy supply is site specific (ibid.). There are three categories of energy sources with relationships with weather/climate variability (VON BREMEN 2010):

1. Geothermal energy is not affected by weather.
2. Bioenergies are related to weather on a seasonal time-scale.
3. Wind power, photovoltaics and solar thermal are directly related to fluctuating weather conditions.

There are numerous advantages in establishing an energy mix, such as compensation for weather-dependent electricity production during seasonal and daily variability. Intermittency affects solar energy, as the production of electricity from solar sources depends on the amount of the solar radiation in a given location. Solar photovoltaics (PV), whether grid connected, stand alone or building integrated, are exposed to variability as a result of seasonal variation from winter to summer, diurnal variation from dawn to dusk and short-term fluctuations from varying cloud cover (IEA, 2007). For that reason, some solar thermal systems make use of heat storage to produce heat when the sun is not shining. Wind power generation, on the other hand, is much stronger in winter than in summer (Heide et al. 2010). The output of wind power is driven by environmental conditions outside the system operator, or generator, control. Energy supply from wind turbines is stochastic in nature and the power produced is proportional to one-third of the speed of the wind (HOLTTINEN 2005). Wind output varies not only seasonally, between summer and winter, but also on shorter time-scales, namely on an hourly basis (HAMACHER ET AL 2004). If wind speed falls to less than approximately 2.5 m/s, the wind turbines will not be able to produce electricity (SCHNELLER 2005). The amount of electricity produced is dependent on wind speeds, air density, and turbine characteristics, among other factors. The impact of intermittency on the electricity grid can be mitigated by grid integration, geographic and technical distribution of generators, and improved weather forecasting techniques (IEA, 2005). A presently common energy mix comprises of photovoltaic panels and solar thermal collectors, providing electricity and heat, which are usually placed on the roof of houses alongside micro wind turbines (which may also be placed in gardens), which produce electricity. Depending on their location, homes with low energy requirements may satisfy their energy needs with these systems alone: solar energy can be stored, while wind energy can immediately supply energy requirements providing the wind turbines are able to collect wind kinetic energy (MOURA & DE ALMEIDA 2010). Furthermore, solar photovoltaics can be combined with geothermal energy. A geothermal heat pump system is a central heating, and/or air conditioning, system that pumps heat to, or from, the ground. This design takes advantage of the moderate temperatures in shallow ground to increase efficiency and minimize operational costs. However, as it is site-specific, geothermal energy has a unique relationship to the land-use planning process, more so than other renewable energy types (DUVARCI & KUTLUCA 2008). Geothermal energy may be combined with solar heating to form a geo-solar system (GEO-SOLAR SYSTEMS 2010, WWW). Depending on the solar radiation measured, the excess energy can be stored underground thus utlilizing less electrical energy in powering the boreholes (ROSINSKI 2007). Another efficient pairing is the combination of solar and biomass energy . During the summer, biomass heating or co-generation systems have a limited time of application as there is no need for space, only water, heating. Therefore an economical and ecologically efficient alternative is that hot water is provided in summer by a PV system. It would not only manage the usual summer hot water demand, but also store surplus energy in storage tanks (ENERGYTECH 2009, WWW).



Figures 3,4: Solar and wind energy combination (CLIMATE 2010, WWW); Solar and geothermal energy combination (SOLAR SERVER 2006, WWW).

2.5 Positive and/or negative planning for integrating energy concerns in new settlement development

Energy consumption and efficiency are key challenges for a sustainable future and need to be considered in the planning and design of new settlement. Planning decisions about land use and development considerably influence energy consumption. For example, urban sprawl generates a greater energy need and raises infrastructure costs than a compact pattern of urban development (Owens 1989). The integration of renewable energy technologies into regional and landscape planning depends significantly on economic, social, and environmental factors. Peker (2004), proposed a form of rational planning which achieves environmental sustainability by using renewable technologies in order to improve life quality, efficiency and the local use of resources. It is essential that regional and landscape planning includes an evaluation of renewable energy potential which takes into account the energy needs of the proposed development. Energy concepts are generally not adequately integrated into planning processes with environmental and economic criteria.

Landscape plans in Italy designate the guidelines and prescriptions regarding designated development/protected areas (see chapter 1.3). Even so, there are some difficulties applying the plans accross levels, in particular in regards to regional directions to local plans. In Germany regional planning (Raumplanung) and landscape planning (Landschaftsplanung) are integrated across all planning levels, where planning decisions are taken under consideration of all plans at all levels. However, unlike in Italy, landscape planning in Germany is not binding (see table 4).

Planning level	Landscape planning	Spatial planning	scale
Federal	Landscape Programme (Landschaftsprogramm)	National spatial planning program – Landesraumordnungsprogramm (LROP)	1:500.000 to 1.200.000
State	Landscape outline plan Landschaftsrahmenplan (LRP)[3]	Regional planning Programme Regionales Raumordnungsprogramm	1:100.000 to 1:25.000
Municipality	Landscape Plan Landschaftsplan (LP)	Land use Plan Flächennutzungsplan (F-Plan)	1:10.000 to 1:5.000
Part of the Municipality	Green Development Plan (Grünordnungsplan (GOP))	Development Plan (Bebauungsplan (B-Plan))	1:2.500 to 1:1000

Table 4: German planning system (KIEMSTEDT ET AL. 1997 IN V. HAAREN 2004: 51, mod.)

Similarly to Italy, the federal state of Germany is composed of a central government (Bund) and a number of constitutive states (Länder) which correspond to the first and second planning levels. The third level is represented by municipalities, local self-governing bodies, which have the right to manage their territory according to the guidelines and directions set by the other, superordinate, levels. Accordingly, spatial and landscape planning are decentralized and different at the three planning levels.

Federal spatial assigns the principles of spatial planning which provide the legal basis for state spatial planning and superordinate specifications for sectoral planning (ARL 2002). State spatial planning is responsible for ensuring that the goals and principles of national spatial planning are met, the acceptance of suggestions from local authorities and the coordination of local development goals

[3] Designations for planning instruments used in Lower Saxony.

with superordinate planning goals within the system of mixed top-down/bottom-up planning. Regional planning is concerned with the detailed elaboration, sectoral integration, and implementation of the goals of state spatial planning. Local urban land-use planning is required to prepare and control, by way of planning guidelines, land use and development. Local planning is carried out on two levels: the preparatory land-use plan and the binding land-use plan.

Landscape planning *is a cross-sectional planning instrument for attaining the goals of nature conservation and landscape management in both settled and non-settled areas* (ARL 2003). Like comprehensive spatial planning, landscape planning covers the entire territory, and is divided into three levels (landscape programme, landscape outline plan and landscape plan). The landscape programme covers sections of state territory (regions), setting out supra-local requirements and the measures to be undertaken in the interests of nature conservation and landscape management, in accordance with the goals of spatial planning. The landscape plan sets local requirements and the measures for attaining the goals of nature conservation and landscape management. Landscape plans are required to be prepared whenever and wherever this is in the interests of nature conservation and landscape management. Under the Federal Nature Conservation Act (1977), landscape plans are required to describe and assess the current, and desirable, future state of nature and landscapes and to designate the necessary measures. In Italy and Germany available sites for the installation of large-scale power plants are identified with both positive planning (e.g. wind potential, according to international standard: 4.5 m / s at 10 m height) and negative planning (exclusion criteria or areas according to spatial and landscape planning) approaches. However, in both areas for new housing development with micro renewable technologies are not identified. As local interests play a crucial role in urban development in Italy, in order to select optimal sites for new settlement in regional and development plans, a land suitability analysis which takes into account environmental concerns, in addition to energy criteria to optimize energy production, needs to be provided. GIS based land suitability analyses may be used to support planning decisions in land use allocation and for the development of planning instruments. By so doing, energy factors in land-use allocation and zoning, together with the participation of decision-makers and policy makers, may be considered.

2.6 A review of GIS based land use suitability analysis

Over the last two decades, international research programs have focused on integrated approaches for sustainable cities. One such example is the International Human Dimensions Programme on Global Environmental Change (IHDP) within the framework of "Cities and Industrial Transformation" which defines an Integrated Assessment as *an interdisciplinary process of combining, interpreting and communicating knowledge pieces from diverse scientific disciplines in such a way that insights are made available to decision makers* (ROCKWELL 1999; ROTMANS 1998). Integrated Assessment has mainly been applied to environmental problems, but it is broadly recognized that it has the potential to address complex problems such as city planning. Thus, the geographic distribution of micro renewable energy potential can be integrated from the start of the planning process, in land use and/or development plans, in order to guide future development to those sites with the best potential of utilizing micro renewable generation. Energy potential estimation would allow regional and urban planners to plan the most efficient energy mix for new housing areas in a given region, optimizing new settlements in terms of multi-functionality. A sustainable approach may also be implemented by identifying the best sites for housing development using different scenarios, according to stakeholder preferences. The most appropriate spatial pattern for future land use can be identified through a suitability analysis according to stakeholder preferences or predictions of activities (HOPKINS 1977; COLLINS ET AL. 2001). The land suitability analysis is one of the most practical applications of GIS for environmental and urban planners (MCHARG 1969; HOPKINS 1977; COLLINS ET AL. 2001). In the context of land suitability, GIS is widely recognized as a useful tool for environmental planners in determining the least, and most, suitable locations for development or resource allocation.

Methods for assessing housing site suitability using GIS

GIS-based approaches to land suitability analysis have been integrated in urban, regional and environmental planning activities (BRAIL & KLOSTERMAN, 2001; COLLINS ET AL., 2001). These approaches have been applied in several situations including in determining the suitability of land for agricultural activities (CAMPBELL ET AL. 1992; KALOGIROU 2002), landscape evaluation and planning (MILLER ET AL. 1998), environmental impact assessment (MORENO & SEIGEL 1988), selecting the best site for public and private sector facilities (EASTMAN ET AL. 1993; CHURCH 2002), and regional planning (JANSSEN & RIETVELD 1990).

The first applications of GIS based approaches to determine land suitability are found in the hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early twentieth century. MC HARG (1969) is recognized as a precursor to the classical overlay procedure in GIS. Three major groups of approaches to GIS- based land use suitability analysis can be identified: (i) computer-assisted overlay mapping, (ii) multicriteria evaluation methods, and (iii) AI (soft computing or geo-computation) methods (cf. COLLINS ET AL. 2001). The **computer-assisted overlay techniques** were developed to overcome the limitations of hand-drawn mapping (MAC DOUGALL 1975; STEINITZ ET AL. 1976). The models are expressed in terms of numerical form like matrices in the computer (MALCZEWSKI, 2004). LYLE AND STUTZ (1983) proposed an application to land suitability analysis for developing an urban land use plan. Boolean operations and weighted linear combination (WLC) are the most common procedures used in the context of map overlay.

In contrast, the **Multi Criteria Decision Making procedures (MCDM)** can be distinguished from overlay techniques by defining the relationships between the input and the output maps (MALCZEWSKI 2004). GIS-based MCDM is defined as a process that combines and transforms spatial and aspatial data (input) into a resultant decision (output). The procedure encompasses: the use of geographical data, the decision maker's preferences, and data and preferences management according to specified decision rules (ibid.). The decision rules can be divided into multi-objective and multi-attribute decision-making methods (MALCZEWSKI 1999). The major difference between both decision-making methods is that multi-attribute objectives are discrete methods as they assume that the number of alternatives (plans) is given explicitly, while the multi-objective methods require alternatives to be generated (they are identified by solving a multi-objective mathematical programming problem). A valuable method for site location is the Analytic Hierarchy Process (AHP), which is recognized by literature as a comprehensive logical, and structural, framework. It allows decision makers to improve their understanding of complex decisions by breaking down the problem by using a hierarchical structure (ibid.).

Recent developments in spatial analysis show that **AI (Artificial Intelligence)** offers new opportunities to land-use suitability analysis and planning (OPENSHAW & ABRAHART 2000). AI is based on modern computational techniques that aid in modeling and describing complex systems for decision-making.

The common denominator of these methods is that, unlike conventional approaches, they are tolerant of imprecision, ambiguity, uncertainty, and partial truth (MALCZEWSKI 2004). In many research areas, GIS and AI approaches, such as fuzzy logic techniques, are combined (WANG ET AL. 1990; BURROUGH & MCDONNELL 1998). The application of fuzzy logic to spatial problems, in general, and land suitability modeling, in particular, can be considered appropriate in defining the boundaries between different land use suitability classes (BURROUGH & MCDONNELL 1998).

Generally, classical overlay mapping and modeling approaches are the most commonly used methods for land suitability analysis in the GIS environment. The major limitation of these approaches is that they fall short on integrating decision-maker preferences into GIS-based procedures. This limitation can be overcome by combining GIS and MCDM methods. The main issues associated with MCDM are related to the choice of method for combining different evaluation criteria, standardizing of criterion maps and the specification of criterion weights (MALCZEWSKI 2004); different methods may produce different results.

GIS-based multicriteria evaluation

Multicriteria evaluation is one of the most common GIS-based tools that to be realized to integrate decision-making in complex problems such as those of site selection, land suitability analysis, resource evaluation and land allocation (VOOGD 1983; NIJKAMP 1986; NIJKAMP ET AL.1990; EASTMAN ET AL. 1993; MALCZEWSKI 1999; GENELETTI 2005). Spatial multi-criteria decision analysis can be considered as a process that converts geographical data (input) into a resultant decision (output). Decision problems that require geographical data are referred to as geographic, or spatial, decision problems (MALCZEWSKI 1999). Spatial problems may be solved MCDM based on GIS. GIS techniques and procedures offer the unique capabilities for automating, managing, and analyzing a variety of spatial data to provide support for spatial decisions (GRIMSHAW 1994). Thus GIS should be considered as a process, rather than as simply software or hardware. Multi-criteria decision-making procedures define a relationship between "input data" and "output data". To solve spatial decisions, a large number of feasible alternatives need be evaluated on the basis of multiple criteria (NIJKAMP 1979; NIJKAMP & RIETVELD 1986 ; CHAKHAR & MOUSSEAU 2008).

Over the last decade it has been argued that GIS and MCDA can potentially improve the collaborative decision-making process by providing a flexible problem-solving framework where stakeholder groups can explore, understand and redefine a decision problem (JANKOWSKI & NYERGES 2001; KYEM 2004; MALCZEWSKI 2006). GIS and MCDA are used for site selection, evaluating various alternatives and selecting the best one by the comparison of scenarios (CARVER 1991). Land suitability analysis is the process of determining whether the land resource is suitable for some specific uses and of determining its level of suitability (STEINER ET AL. 2000). Spatial multicriteria analysis requires information on criterion values and geographic locations, in addition to decision-maker preferences according to a set of evaluation criteria. This means that analysis results depend not only on the geographic distribution of attributes, but also on the stakeholder value judgments involved in the decision-making process (see Figure 5). Therefore, two components are significant for spatial multi-criteria decision analysis: (1) the GIS component (e.g. data acquisition, storage, retrieval, manipulation), and (2) the MCDM analysis component (e.g. aggregation of spatial data and decision-maker preferences (CARVER, 1991; JANKOWSKI, 1995).

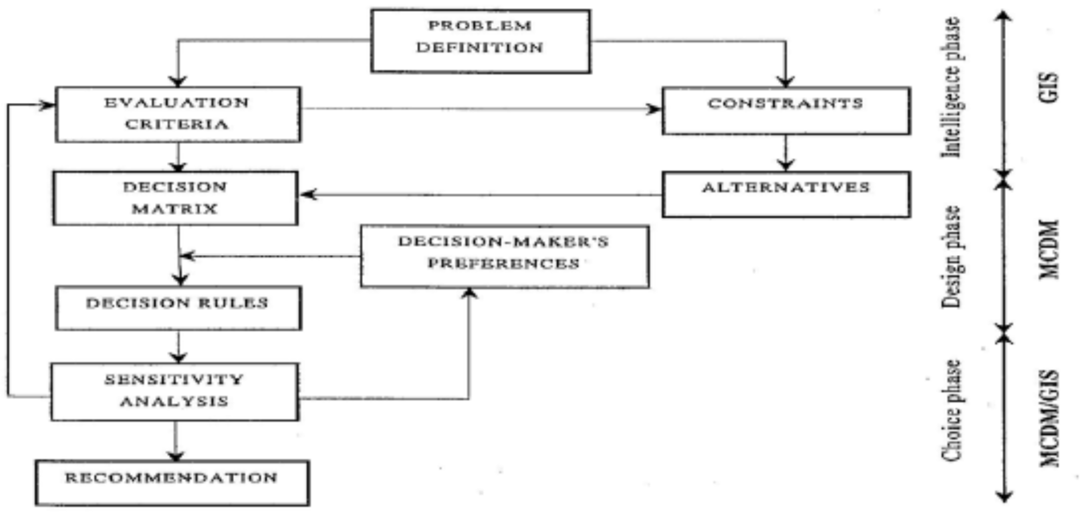


Figure 5: Decision flowchart for spatial multicriteria analysis (Malczewski, 1999).

Geographic Information Systems (GIS)

Geographic information systems (GIS) have emerged as useful computer-based tools for spatial description and data storage and manipulation. GIS can perform several tasks by utlising spatial and attribute data. Such functions differentiate GIS from other management information systems (LAURINI & THOMPSON 1996). The concept of GIS application is developed through map processing. It is based on the generation of a number of base maps that are created through digitizing, geo-referencing and entering data that describes their characteristics (HYWOOD ET AL. 2006).

GIS allows decision-makers to work with layers of spatial data and commands of operation processes to identify suitability locations. Carver (1991) believes that GIS provides decision-makers with a powerful set of tools for the manipulation and analysis of spatial information. However, while GIS allows the decision maker to identify a list of sites meeting a predefined set of criteria (JIANG & EASTMAN 2000), it does not allow decision-makers the flexibility to modify the importance of each criteria in the context of either a single, or multiple, set of objectives. This restriction in terms of choice or preference can be solved by using multi-criteria evaluation methods (see JANSSEN 1992).

Multi-criteria evaluation methods

Over the last two decades, several multi-criteria GIS-based evaluation methods have been developed. They include weighted linear combination (WLC) (JANSSEN AND RIETVELD 1990; EASTMAN 1997), analytical hierarchy process (AHP) (BANAI 1993; EASTMAN 1997), concordance-discordance analysis (CARVER 1991; JOERIN ET AL. 2001) and ideal point methods (CARVER 1991; JANKOWSKI 1995; PEREIRA AND DUCKSTEIN 1996). Among these procedures, WLC and Boolean overlay operations, such as intersection (AND) and union (OR), are considered the most often used (MALCZEWSKI 1999). These operations have been generalized using the Ordered Weighted Averaging (OWA) concept developed by Yager (1988).

Ordered Weighted Averaging (OWA) involves two sets of weights: criterion, or importance weights, and order weights (BOROUSHAKI AND MALCZEWSKI 2008). A criterion weight is assigned to a given criterion or attribute for all locations in a study area to indicate its relative importance, according to decision-maker preferences, in the considered set of criteria. The order weights are associated with the criterion values on a location-by-location basis. They are assigned to a location’s attribute values in decreasing order with no consideration of the attribute source of each value. The re-ordering procedure involves associating an order weight with a particular ordered position of the weighted attribute values. The first order weight is assigned to the highest weighted attribute values for each location, the second order weight to the second highest values, and so on. OWA is an aggregation technique based on the generalization of three basic types of aggregation functions: (1) operators for the intersection of fuzzy sets, (2) operators for the union of fuzzy sets, and (3) averaging operators. It provides continuous fuzzy aggregation operations between the fuzzy intersection and union, with a weighted-average combination falling midway in between. One of the main features of OWA is that it allows decision-makers to modify the form of attribute (criterion) combinations from a minimum-type (logical AND) combination through all intermediate types (including WLC), to a maximum-type (logical OR) combination (YAGER 1988; JIANG AND EASTMAN 2000). Order weight is also associated with a trade-off measure indicating the degree of compensation between criteria. The parameters associated with the OWA operations provide a mechanism for guiding the GIS-based land-use suitability analysis. The WLC is just one variant of the OWA technique.

Weighted linear combination (WLC) or simple additive weighting is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average (CARVER 1991; RAO ET AL. 1991; EASTMAN 2006). The decision-maker assigns the weights of relative importance directly to each attribute map layer. The full amount of the score for each alternative is achieved by multiplying the importance weight assigned to each attribute by the scaled value given for that attribute to the alternative and then summing the products over all attributes. The scores are calculated for all of the alternatives and that with the highest overall score is chosen. The method can be applied using any GIS system and allows the evaluation criterion map layers to be combined in order to identify the composite map layer becomes the output. The methods can be implemented in both raster and vector GIS environments.

Analytical hierarchical process (AHP) is *a comprehensive, logical and structural framework, which allows [us] to improve the understanding of complex decisions by decomposing the problem in a* *hierarchical structure* (SAATY 1980). Location decisions are representative multi-criteria decisions that require the prioritizing of multiple criteria. Saaty (1980) has shown that this weighting can be dealt with using a theory of measurement in a hierarchical structure. The AHP allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the aims, criteria and eventually alternatives. AHP can be utilized in two different ways within the GIS environment: firstly, it can be employed to calculate the weights associated with the criteria, and secondly, it can be used to aggregate the priority for all hierarchical levels, including the level representing alternatives (SAATY 1977). Such multi-criteria decision problems are typical for housing site selection.

Concordance-discordance analyses are methods in which each pair of alternatives, either raster pixels or polygons, is analyzed for the degree to which one outranks the other in the specified criteria (CARVER 1991; NIJKAMP ET AL. 1990; JOERIN ET AL.2001). Concordance methods are based on a pairwise comparison of alternatives. They produce an ordinal ranking of the alternatives; that is, when two alternatives are compared, these methods can only express that alternative A is preferred to alternative B, but cannot indicate by how much.

Ideal point methods are methods, which order a set of alternatives on the basis of their distance from an ideal point. This point represents a hypothetical alternative that consists of the most deliverable weighted standardized levels of each criterion across the alternatives under consideration (JANKOWSKI 1995; PEREIRA AND DUCKSTEIN 1993). The alternative that is closer to the ideal point is the best alternative.

The limitations of MCDM involve criteria of varying importance to decision-makers. The relative importance of the criteria is normally achieved by assigning a weight to each criterion. The derivation of weights is a fundamental step in determining decision-maker preferences. A weight can be defined as *a value assigned to an evaluation criterion indicative of its importance relative to other criteria* *under consideration* (MALCZEWSKI 1999). There are four main groups of techniques for the development of weights (ibid.):

- *Ranking methods*, which consider every criterion ranked in the order of decision-maker preferences

- *Rating methods,* which require the estimation of weights on the basis of a predetermined scale

- *Pairwise comparison methods,* which involve pairwise comparison to create a ratio matrix

- T*rade-off analysis methods,* which make use of direct trade-off assessments between pairs of alternatives.

2.7 Multicriteria analysis in Europe

Geoprocessing systems are able to support decision-makers faced with complex spatial problems by providing a flexible, problem-solving environment. Planning problems can be explored to increase levels of understanding and to generate possible alternative solutions. This enables decision-makers to investigate possible trade-offs and to identify individual characteristics of possible solutions. Spatial decision support systems (SDSS), ascribed to Geographic Information Systems (GIS), are designed to support a decision research process for complex spatial problems (DENSHAM & ARMSTRONG 2003). Cartographic visualization is one of the most important tools which aids in identifying solutions for complex problems by developing the decision support capabilities of GIS through the integration of maps with multiple criteria decision models (ibid.). Maps have been used as decision support tools as new developments of spatial multi-criteria decision support methods have increased the need of combining computational decision support tools with interactive map visualization (MALCZEWSKI 1999).

The mapping and visualization techniques of GIS-MCDM include map modeling by using GIS in evaluating site-location choice alternatives on the basis of suitability criteria. (Malczewski 1999). Various prototypes (CARVER 1991; CHURCH *ET AL.* 1992; FABER *ET AL.* 1995; JANKOWSKI AND EWART 1996) have been developed. MCDM tools have been integrated in the GIS environment (for example the IDRISI software Eastman 1997) or GIS functions (such as spatial data query or mapping) and have been introduced in MCDM software (Fisher *et al*. 1996). However, existing tools have a limited use in map-based decision problems. Despite some original maps having been proposed for supporting site selection decisions (ARMSTRONG *ET AL*. 1992), maps have generally been used to display the evaluation results and not to structure decision problems (JANKOWSKI ET AL. 2001). Maps, as analytical tools in spatial decision analysis, have been not thoroughly investigated. SDSS, for example, usually combines rich spatial and aspatial information, such as data on transport, land use, economics, environmental issues, population, resource management and development (ibid.). Furthermore, models produce different scenarios which can be useful in analyzing different spatial policy options according to information and data available. These techniques allow spatial planners to investigate the effects of different scenarios and to easily adapt the system with simple modifications.

In Europe, as in Italy, land management and planning needs to consider different land users (agronomy, economy, forestry, etc.) and their corresponding, often strong and incompatible, requirements. By modifying the decision process os that all actors have the opportunity to participate, the so-called NIMBY (Not In MY Back Yard) reaction can be minimized. The sustainability of new development projects is dependent on the integration of local knowledge with the scientific input of experts (e.g. regional and urban planners) in the decision-making process (RINNER ET AL. 2008). Sustainable development through spatial planning is characterized by the consensus obtained between all stakeholders, in the sense that the chosen decision alternative is perceived to be acceptable by the majority (BENDER & SIMONOVIC 1997). In Italy, GIS and multi-criteria analysis were used for evaluating and mapping erosion and landslides hazards (CAVALLO & VARESE 2001) and for site selection (ZUCCA ET AL. 2008).

MEDUSAT model is a structured application of GIS and multi-criteria analysis for land managers (JOERIN ET AL. 1998). Because of the very short time-frame of decisions, land suitability maps were created as a decision tool for public administrations. MEDUSAT involves stakeholders in the decision making process in two different ways. Firstly, different stakeholder groups can negotiate the subjective parameters, and argue on the attributed weight, before associating them with each criterion through the adoption of a common set of values. Secondly, the multi-criteria analysis needs to be repeated to select, for each individual stakeholder group, a solution that is coherent to its needs. The result of the multi-criteria analysis is a map describing, for instance, the most suitable areas. Stakeholder groups can then discuss and negotiate further by overlaying and comparing these maps, which are a spatial representation of their own preferences.

In the **SSHORT** (Sustainable Social Housing Refurbishment Technologies) project (2003), partly funded by the European Commission in the frame of the 5th RTD program, the aim was to integrate sustainable energy technologies in the refurbishment of social housing. To achieve that, a multi-criteria decision-making tool, called System Selection Tool, was developed for supporting decision-makers in choosing the most appropriate energy technological solutions for housing refurbishment (ALANNE & KLOBUT 2003). The decision-making was based on the needs and requirements of the owners and occupants of the buildings. The designer had the responsibility to follow the orders and directions of authorities in order to ensure compatibility with regulations and laws (ibid.). Experienced designers could also bring into consideration other factors so that decisions were made in cooperation with building project participants. This tool was applied to assess different scenarios by analysing the effects of variations of the diverse options.

3. Objectives and research questions

This thesis focuses on the integration of renewable energy efficiency from solar, aeolic, biomass and geothermal sources in new housing development by first estimating the geographic distribution of micro renewable potentials at regional/sub-regional level. This information is then integrated with environmental and landscape criteria in a systematic, methodological approach to identify optimal housing locations. Both tasks, sustainably locating new housing development and optimizing the mix of micro renewable, should be facilitated by this method. The integration of renewable energy efficiency from solar, aeolic, biomass and geothermal resources into new housing development is directed by regional land use plans and/or local development plans.

The main research questions investigated are:

- How to calculate the geographic distribution of energy potential for local application? How to produce energy potential maps? Which criteria and algorithms are needed for identifying the theoretical energy potential for different energy sources?
- How to support decision-makers, or planning, in the task of including multiple further criteria into housing development decisions? Which data is available in the Region of Sardinia to include environmental impact assessment?
- Which environmental and landscape criteria are considered relevant for the assessment of new housing development with micro renewable technologies?

The overall objective of the research is to develop a methodology that, on the basis of micro energy potential and environmental and landscape criteria, identifies optimal sites for planning new multifunctional urban settlements with the lowest possible environmental impact in a GIS environment that is adapted to Italian planning and data conditions. Accordingly, in the first part of this work, existing or new developed methods were applied to estimate the micro renewable energy potential. In the second part, suitability areas for new settlements with micro-renewable technologies, consistent with expert preferences, are generated using the AHP pairwise comparison method. The eastern metropolitan area of Cagliari in the south of Sardinia, Italy was selected as a case study area for developing and testing the approach.

4. Methodology and data

4.1 General methodological approach

A new methodological approach was developed based on existing methods for energy potential assessment. These existing methods were pre-tested in the region of Hannover by the author and a number of master students, in cooperation with the State Office for Mining, Energy and Geology (LBEG), under the supervision of Prof. Christina von Haaren and Prof. Michael Rode of Leibniz Universität Hannover, Germany (BREDEMEIER ET AL. 2009) as well as in the metropolitan area of Cagliari test region in the work of the present dissertation. The methods were adapted to local/regional scale planning. This resulted in the assessment of the theoretical potential which describes the theoretically available energy supply within a selected region in a given period. Because of existing technical, ecological, economic and social restrictions, the theoretical potential can be exploited only up to a certain percentage (RODE ET AL. 2005; STEINBACH 2002).

Expert preferences were used for weighting environmental assessment criteria. This resulted in modeling housing development which is optimized under multiple criteria. The expert preferences were taken from a survey conducted with students, academic planners, regional planners and public authorities in Italy, Germany and United Kingdom. This second methodological approach has been chosen for the following reasons:

- In most European countries, there are no clear cut standards regarding the suitability of micro generation in residential areas (in contrast to emission standards, for example) nor pre-defined decision priorities regarding suitable locations; thus using expert opinions proved a simple way of priority setting in complex decisions.

- The planning process is supported as general preferences of decision-makers can be automatically translated into spatial scenarios;
- The method can be used for modeling the consequences of different preferences and allows for including local or regional stakeholder opinions and interests.

The multi-criteria approach along with expert preferences was chosen after an analysis of the Italian planning system and the practice of building new urban areas in Sardinia. The planning system is sound, in principle, in regards to the hierarchical structure. Regions are responsible for regional planning within their boundaries according to national guidelines and laws. Cultural and natural landscapes are considered at regional level in the Regional Landscape Plan. At the local level, municipalities are responsible for environmental, urban and land-use planning which needs to accord with the higher levels. However, decisions are chosen at local level where they are influenced by local interests such as new investment for tourism, for example. For this reason, a positive planning approach similar to multi-criteria evaluation was chosen. In order to guide future settlement development according to expert preferences and the principles of sustainability, it was deemed more appropriate for Italian conditions and practices.

To identify the optimal sites for energy efficient housing development by a GIS based multi-criteria analysis, at regional scale, the following steps were implemented:

1. Estimating the theoretical energy potential for each micro-renewable energy source (solar, wind, wood biomass and geothermal).
2. Expert survey:

   a) Identifying preferred sites for new housing development as chosen by students, academic planners, regional environmental planners and public authorities from Italy, Germany and the UK.

b) Determining the preferred sites for new housing development with renewable micro technologies, as chosen by experts.

3. Processing the data from gathered at step 2.

4. Combining GIS maps gathered from Steps 1 and 2 to obtain final maps depicting optimal sites for new energy efficient residential areas.

The method is divided into (i) positive planning (i.e. areas of expert interest according to environmental and landscape criteria) and (ii) negative planning (i.e. energy potential estimation, restrictions on areas such as water and environmentally valuable areas). The approach is based on the application of GIS. The integration of all data formats into a GIS database system, in a multi-criteria evaluation process, guides towards the goal of decision-making by selecting the most suitable scenario, or scenarios.

Research Steps	**Research questions**	**Methods**	**Data**
Which methods need to be applied, or developed, to estimate the theoretical energy potential for each micro-renewable energy (solar, wind, wood biomass and geothermal energy), in order to obtain raster maps (geographical distribution of energy potential)?			
Solar energy potential Wind energy potential Geothermal energy potential Biomass Energy potential	Which criteria have to be considered to estimate the energy potential? Which algorithms are needed for identifying the theoretical energy potential? Which data are required? Is the data accurate for estimating the energy potential on the regional scale? Which software, compatible with ARC GIS, is available, and suitable, in terms of scientific validity?	State of the art research methods Analysis of the main methods used for the estimation of micro-energy potential Case studies analysis	Digital Elevation Model DEM 90 Wind speeds 25 m Geological Map Land use Map Protected areas Natura 2000 Sites
Which methods need to be applied to create raster maps for identifying the preferred sites for new housing development, as chosen by experts? Which methods need to be applied to select the preferred sites for new housing development using renewable micro technologies, as chosen by experts?			

Expert survey (questionnaire)	Which criteria are to be selected for sustainable urban development? Which criteria are to be selected in order to consider the environmental and landscape impacts of micro technologies? Which experts are to be addressed with the questionnaire? What are the differences between expert preferences? What are the differences between expert preferences and energy potential? What are the differences between energy potential and micro-renewable preferences?	Analysis of the European Spatial Development Perspective (ESDP), the Regional Landscape Plan of Sardinia and the development guidelines of the City of Hannover. Research about the environmental and landscape impact of micro-generators. Statistical analysis Comparison between the maps obtained from expert preferences.	Weight for each criteria obtained by the questionnaire
How do raster maps need to be combined in order to obtain the final raster maps showing the optimal sites for new energy efficient residential areas? Which are the best locations for new energy efficient settlements? How can different micro-renewables be combined? What are the consequences of this method for future housing development based on this new approach? What will be the next step for research?			
Results maps depicting the best location for new housing development with micro-renewable technologies.	What do the results suggest about how future residential development should take place in the study area? Which areas need to be excluded? According to the expert opinion, should any residential development on environmentally valuable and vulnerable areas take place? Which micro-renewables can be combined? Which are antagonistic? Which combinations do experts prefer and why? What are the requirements for data availability, validity and precision? Are the results accurate? What are the advantages and disadvantages of this method? How can it be improved? Is it possible to use this method for building scenarios for future development? How can better results be achieved? What will be the next step?	Comparison of the results with the Sardinian Landscape Plan Evaluation of results	Weight for each criteria obtained by the questionnaire

4.2 Adaptation of existing methodology for identifying spatial solar energy potential

Solar energy is the solar radiation that reaches the Earth. This energy can be converted into heat, by solar thermal collectors, and electricity production, by photovoltaic panels. The strength of solar radiation which reaches the Earth's surface depends on location latitude, with the highest values found in the tropics and the lowest around the poles (HOFIERKA & CEBECAUER 2008). Solar radiation is influenced by astronomic factors such as the Earth's geometry, revolution and rotation (its declination, latitude and solar hour angle). Factors which contribute to atmospheric attenuation (scattering or absorption) are gases (i.e. air molecules, ozone, carbon dioxide and oxygen), solid and liquid particles (aerosols, including non-condensed water) and clouds (condensed water) (JRC 2010a, www). The reaching the Earth's surface is also affected by its terrain topography, namely the slope inclination and aspect, in addition to shadowing effects of neighbouring terrain features. The elevation above sea level determines the attenuation of radiation by the thickness of the atmosphere. Geographical factors and spatial and temporal distribution of renewable energy resources require map-based assessments to identify available solar resources (ŠÚRI ET AL. 2006). The solar potential raster maps were calculated using open-source solar radiation tools, including the *r.sun* solar radiation model and the PVGIS estimation utility, derived from the Photovoltaic Geographical Information System Interactive Maps (Joint Research Center of the European Commission 2010a, WWW). The web-based estimation utility provides an on-site assessment of potential PV electricity production for Europe and Africa. The PVGIS calculation of PV potential for a specific site is based on spatial data automatically taken from the PVGIS database. The database is based on climatic data from 566 meteorological stations covering the 1981–1990 periods and includes monthly averages of daily sums of global and diffuse irradiation and Linke atmospheric turbidity. Elevations and terrain features are represented by a 1-km digital elevation model. More details about the European solar database implemented in the PVGIS estimation utility can be found on its website (ibid.). The *r.sun* model an estimation of global solar radiation (beam, diffuse and reflected), for both clear sky and overcast atmospheric conditions from the digital elevation model (DEM) (ŠURI ET AL. 2006). An important factor in producing reliable maps of solar irradiation was the estimation of sky cloud coverage, as the total amount of cloud cover significantly affects ground irradiation. For this reason, the data was validated using PVGIS. The output of this model is a raster map of the global irradiation annual average for a horizontal surface.

The *r.sun* model

The *r.sun* solar radiation model, a GRASS GIS *plugin* developed by Sùri and Hofierka (2002), is a flexible and efficient tool for the estimation of global solar radiation (beam, diffuse and reflected) for clear sky and overcast atmospheric conditions (SÚRI & HOFIERKA 2004). While the calculation of the beam component is straightforward, different literature varies in its treatment of the diffuse component, resulting in various models (PEREZ ET AL. 1987). This component is dependent on climate and regional terrain conditions and is often the largest source of estimation error. The effect of cloud cover is not directly taken into account, but could be incorporated by averaging cloud coverage data from meteorological station datasets. The clear-sky solar radiation model, applied in the *r.sun* model, is based on equations published in the European Solar Radiation Atlas (ESRA) (SCHARMER AND GREIF 2000; PAGE ET AL. 2001; RIGOLLIER 2001). An algorithm used to calculate solar irradiation is implemented in the Open Source GIS software GRASS, where beam irradiance normal to the solar beam *B0c* [W·m-2] is attenuated by cloud coverage of the atmosphere and calculated per equation (1) (JRC 2010a, WWW):

$$B_0c = G_0 \exp \{-0.8662\ TLK\ m\ dR(m)\} \qquad (1)$$

Where:

G_0 is the extraterrestrial irradiance normal to the solar beam [W/m^2];

-0.8662 TLK is the atmospheric turbidity factor; m is the "optical air mass"; and

dR(m) is the "Rayleigh optical thickness at air mass m".

In contrast to other models, the *r.sun* model is able to compute solar irradiation for large areas with complex terrain. For instance, in 2004 the model was applied to estimate the solar potential for photovoltaic systems in Central and Eastern Europe and was consequently utlilized to make long-term calculations at map scales varying from the continental to the local (SÚRI & HOFIERKA 2004).

Input parameters

The *r.sun* model operates in two modes that may be used separately or combined to furnish estimates for any requested time-frames or intervals. In *mode 1,* the model calculates raster maps of chosen components (beam, diffuse and reflected) of solar irradiance [$W.m^{-2}$] and solar incident angles [degrees]. In *mode 2*, the raster maps of the daily sum of solar irradiation [$Wh.m^{-2}.day^{-1}$] are computed by integrating irradiance values calculated over a given day. In *mode* 2, raster maps representing the annual average of daily sums of global irradiation for horizontal surfaces were required. To compute the irradiation raster maps (*beam_rad*, *diff_rad*, *refl_rad),* the *r.sun* model requires only a few mandatory input parameters: a digital terrain model (showing elevation, slope, aspect – *elevin*, *slopein*, *aspin*), day number (*day)* for *mode 2*, and local solar time (*time) for mode 1*. Other input parameters are either internally computed, or the values can be set to fit specific user needs; Linke atmospheric turbidity, ground albedo, beam and diffuse components of clear-sky index, and time step used for calculation of all-day irradiation (SÚRI & HOFIERKA 2004). Solar declination is computed internally using day number, unless an explicit value of *declin* is used. In the case that user data is localized in GRASS location with a defined projection, *r.sun* uses an internal GRASS function to obtain geographical latitude for every raster cell (GRASS 6.3 user manual). Linke turbidity factor and ground albedo can be set as spatially averaged single values *(lin*, *alb)*, or spatially distributed parameters *(linkein*, *albedo)*. A default single value of Linke factor is *lin*=3.0 and is near the annual average for rural-city areas. The Linke factor for a clear atmosphere is *lin*=1.0 (GRASS 6.3 user manual). To avoid the overestimation of irradiance, the -s flag is used to account for the relief effect.

The table 5 presents a list of all input parameters

Parameter name	**Type of input**	**Description**	**Mode**	**Units**	**Interval of values**
elevin	raster	elevation	1, 2	meters	0 – 8900
aspin	raster	aspect (solar panel azimuth)	1, 2	decimal degrees	0 – 360
slopein	raster	slope (solar panel inclination)	1, 2	decimal degrees	0 – 90
linkein	raster	Linke atmospheric turbidity	1, 2	dimensionless	0 - ?7
lin	single value	Linke atmospheric turbidity	1, 2	dimensionless	0 - ?7
albedo	raster	ground albedo	1, 2	dimensionless	0 – 1
alb	single value	ground albedo	1, 2	dimensionless	0 – 1
latin	raster	latitude	1, 2	decimal degrees	-90 – 90
lat	single value	latitude	1, 2	decimal degrees	-90 – 90
coefbh	raster	clear-sky index for beam component	1, 2	dimensionless	0 – 1
coefdh	raster	clear-sky index for diffuse component	1, 2	dimensionless	0 – 1
day	single value	day number	1, 2	dimensionless	0 – 366
declin	single value	solar declination	1, 2	radians	-0.40928 – 0.40928
time	single value	local (solar) time	1	decimal hours	0 – 24
step	single value	time step	2	decimal hours	0.01 – 1.0
dist	single value	sampling distance coefficient for shadowing	1, 2	dimensionless	0.1 – 2.0

Table 5: *r.sun* input parameters

Model outputs

The r.sun program automatically distinguishes two operating modes by considering the input parameters. Calculation in *mode 1* computes the solar incident angle *incidout*, and **solar irradiance** raster maps *beam_rad*, *diff_rad* and *refl_rad*. When *mode 2* is selected, the model provides cumulative raster maps of **solar irradiation** (*beam_rad*, *diff_rad* and *refl_rad)* within a set day. Moreover, it is possible to compute insolation time (*insol_time)*.

The incidence angle, irradiance [$W.m^{-2}$] and irradiation [$Wh.m^{-2}.day^{-1}$] maps can be computed without taking into account the terrain shadowing effect or considering the shadows by setting the *-s* flag. Other information (solar declination, extraterrestrial irradiance, interval of used Linke turbidity and ground albedo etc.) can be found in a r.sun local text file (*r.sun_out.txt*).

The table 6 presents a list of all output raster maps.

Parameter name	**Description**	**Mode**	**Units**
incidout	solar incidence angle	1	decimal degrees
beam_rad	beam irradiance	1	$W.m^{-2}$
diff_rad	diffuse irradiance	1	$W.m^{-2}$
refl_rad	ground reflected irradiance	1	$W.m^{-2}$
insol_time	duration of the beam irradiation	2	min.
beam_rad	beam irradiation	2	$Wh.m^{-2}.day^{-1}$
diff_rad	diffuse irradiation	2	$Wh.m^{-2}.day^{-1}$
refl_rad	ground reflected irradiation	2	$Wh.m^{-2}.day^{-1}$

Table 6: *r.sun* output parameters

4.3 Adaptation of existing methodology for identifying spatial wind energy potential

Wind energy is a converted form of solar energy. The movement of air masses in the atmosphere is dependent on the heating of the earth by the sun. Radiation from the sun is absorbed and reflected variably by the earth's surface, as it varies with geographic land distribution (e.g. land, water, forest, etc.) and the time and day (PETERSON & HENNESSEY 1978). For instance, ice surfaces reflect the most sun light, while the vegetation absorbs a significant amount of light. This non-uniform heat absorption produces notable differences in the atmosphere with respect to temperature, density and pressure. One of the most important phenomena, with respect to the utilization of wind energy, is the increase in wind speed with altitude. The friction of moving air masses against the earth's surface reduces the wind speed from an undisturbed value at high altitude (geostrophic wind) to zero at ground level (KEMPTON 2010). At greater altitude, the air moves along lines of equal pressure (*isobars*). The lowest part of the atmosphere above the ground is known as the *boundary layer*. The principal effects governing the properties of the boundary layer are: the strength of the geostrophic wind, and the surface roughness responsible for the turbulence phenomena. The presence of obstacles (such as trees, rocks or buildings) produces strong turbulence which affects the efficiency of turbines. Some local winds may instead be generated by thermal effects such as the difference in the heat of land and water surfaces. Wind flows are influenced by small-scale topographic situations. One example is found in mountain slopes which face the sun and are therefore heated more quickly than those that do not (ibid.). Therefore, reliable wind data maps are needed to plan the use of wind turbines. To create wind energy potential maps, the wind speeds at 25 m with 1 Km resolution from the ground level were used. The data was derived from the Italian Atlas of Wind Energy ("Atlante eolico italiano" 2002) developed by the Genoa University and the CESI research centre. Factors such as roughness (relief and land characteristics), height above sea level and geographical location were considered in the estimated average annual wind speeds of the Italian Wind Atlas. The final wind raster map, with a 1km resolution, was rescaled on a Digital Elevation Model (DEM) 90 m in accordance with the following logarithmic height equation (Eq. 2) (HAU 2006), which represents a conventional approach to describing the increase in wind speed with height:

$$v = v_{ref} \ln(z/z_0)/\ln(z_{ref}/z_0) \qquad (2)$$

Where:

v = wind speed at height z above ground level;

v_{ref} = reference speed, i.e. a wind speed we already know at height z_{ref};

z = height above ground level for the desired velocity, v.;

z_0 = roughness length in the current wind direction; and

z_{ref} = reference height, i.e. the height where the wind speed is measured v_{ref}.

Equation 2 assumes that the atmosphere is in a neutral stability condition (i.e. that the ground surface temperature is equal to to air temperature).

The relationship between wind speed and altitude can be described using a power law approximation (Eq. 3).

$$v = v_{ref} (z / z_{ref})^{\alpha} \qquad (3)$$

The exponent, α, is an empirically derived coefficient that varies depending on the stability of the atmosphere. For neutral stability conditions, α is approximately 0.143 (COUNIHAN 1975; TOUMA 1977) .

α is usually assumed to be constant, as it does not introduce substantial errors into the estimates (when considering atmospheric layers < 50 m) if there are no trees or structures present in the study area to disturb near-surface wind (ROBESON & SHEIN1997). However, when a constant exponent is used, it does not take into account the roughness of the surface, the displacement of calm wind from a higher level from the surface due to the presence of obstacles, and the stability of the atmosphere (COUNIHAN 1975; TOUMA 1977). It has been shown that an exponent of 0.11 is more appropriate over open water (e.g. for offshore wind farms) and 0.143, is more applicable over open land surfaces (HSU ET AL. 1994).

4.4 Adaptation of existing methodology for identifying spatial geothermal energy potential

Geothermal energy is energy stored, in the form of heat, beneath the surface of the solid earth. This definition became official in Germany (VDI 4640) and has been adopted by the European Geothermal Energy Council (EGEC). A ground source heat pump can be defined as a heating, and/or cooling, system that operates by utlizing the earth as a heat source (in winter) or a heat sink (in summer). Depending on latitude, the upper three meters of the Earth's surface maintain an almost constant temperature between 10 and 16°C (GEOBERICHTE 5 2007). In winter, the heat pump extracts the heat from the ground and transfers it to the building. In the summer, the process is inverted and the heat pump extracts heat from the building and transmits it to the ground. Ground source heat pumps have a heat exchanger in contact with the ground, or groundwater, to extract, or dissipate, heat. Direct exchange systems circulate a mixture of water and antifreeze around a loop of pipe, called a ground loop, which is buried in the garden, while open loop systems use natural groundwater (GEOTHERMIEZENTRUM BOCHUM 2008). Heat from the ground is absorbed into this fluid and is pumped through a heat exchanger in the heat pump. In this work, vertical and horizontal closed loops systems were considered (see Figure 6).

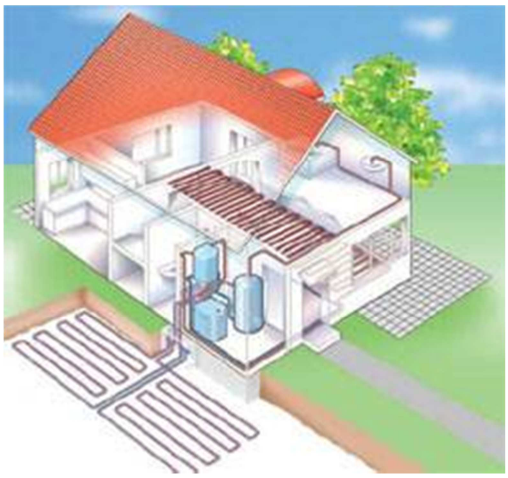


Figure 6: Geothermal horizontal loops (source: ACCLIMATIZE 2010)

The consideration of the physical rock properties is crucial for the estimation of specific heat extraction values. It corresponds to potential energy needed for the use of borehole heat exchangers (vertical loops) and horizontal ground heat exchangers (horizontal loops). The specific heat extraction value is measured in watts per meter [W/m], for vertical loops, and in watts per square meter

[W/m^2], for horizontal loops. The specific heat extraction value is the heat that could be extracted from the soil and is varied by rock characteristics and water content (KALTSCHMITT et al. 2008: 23). This value is influenced by various geothermal parameters (heat conductivity, soil temperature, heat capacity and rock density); although heat conductivity [W/(m * K)] is the primary geophysical parameter. This parameter is related to water, dry bulk density (dry density) and soil type (ibid.). The heat conductivity of the subsurface is especially dependent on mineral composition, granularity (sand or clay), and porosity. Air is a bad heat conductor, then the dry area above the ground-water level got only a small heat conductivity (**LANDESAMT FÜR NATUR UND UMWELT DES LANDES SCHLESWIG-HOLSTEIN 2006).** Specific studies on site (e.g. the Thermal Response Test) are required for detailed plant design or dimensioning of major facilities.

The geothermal energy potential maps were obtained by considering the physical rock properties for the estimation of specific heat extraction values which correspond to the potential energy needed for the use of borehole heat exchangers (vertical loops). The regional geological map (at 1:250.000 scale), the Corine Land Cover and a vector map for the soil suitability irrigation of Sardinia, were used to identify rocks types to 1.3 m when considering horizontal loops. The geological stratification of rocks to 100 m (for the vertical loops) was derived using the regional geological map and a formula proposed by Kaltschmitt et al. (2006) (4) which calculates specific heat extraction. Based on the heat conductivity of the rocks, the specific heat extraction capacity was calculated using equation 4.

$$P_{EWS} = (13 \cdot \lambda) + 10 \qquad (4)$$

Where:

P_{EWS} = specific heat extraction capacity, and

λ = heat conductivity of the rock.

Two experts Geologist Fausto Pani, and Prof. Giovanni Barrocu of Cagliari University,) were consulted to obtain an estimate of geological stratification.

Two types of potential maps for near-surface geothermal micro generation were obtained. The first were energy potential maps for borehole heat exchangers (vertical loops), and the second were energy potential maps for horizontal ground heat exchangers (horizontal loops).

4.5 Developing a methodology for identifying the spatial biomass energy potential

Given the thesis focuses on housing development, wooden biomass is the most relevant for consideration as it is suitable for producing heat and electricity with the installation of cogeneration systems. Important criteria for identifying potential are the distance of the source of wood from the settlement and the capacity of the forest supply, in terms of the wood reservoir. From an economic perspective, the energy efficient use of biomass can be defined as use within a 30 km radius from a potential biomass facility (GERLINGER 2008: oral.). Because of the extension of the eastern metropolitan area of Cagliari relative to a radius of 30 km, the range of biomass energy efficiency was adjusted to within a radius of 15 km from a potential biomass facility. Furthermore, because of the time available, it was not possible to include factors such as road-types and road-states alongside variable factors such as gasoline prices for wood transport in a consideration based on a 30 km-radius. These factors could be better considered in a more detailed view. After the exclusion of Natura 2000 sites, or other sites where wood use is prohibited, all forests were extrapolated for constructing a raster map, which was then used to calculate the theoretical energy potential for wood biomass energy. In order to identify the wood bioenergy potential and to differentiate between areas of varying potential, a Monte Carlo method, or simulation, is applied (KALOS & WHITLOCK 1986).

Monte Carlo Method

A Monte-Carlo method can be defined as *any method which solves a problem by generating suitable random numbers and observing that fraction of the numbers obeying some property or properties* (WOLFRAM MATHWORLD 2010, WWW). This problem solving technique is used in many fields of application for achieving numerical solutions to problems that are too complex to solve analytically. A Monte Carlo method approximates the probability of certain outcomes. Therefore, multiple trial runs, called simulations, were run using random variables. This process describes a stochastic model in which the inputs are generated randomly from a probability distribution to simulate the process of sampling from an actual population (KALOS & WHITLOCK 1986: 3; WITTWER 2004, WWW). In this work, **Monte Carlo integration,** or the numerical integration using random numbers, was used. Monte Carlo integration methods are *algorithms for the approximate evaluation of definite integrals, usually multidimensional ones* (UEBERHUBER 1997: 124). In this case, this is the sum of forest areas. Regular algorithms evaluate the integrand at a regular grid. Monte Carlo methods, however, randomly choose the points at which the integrand is evaluated (ibid.). Monte Carlo methods use random samplings to approximate probability distributions. One use for Monte Carlo methods is in the approximation of integrals. This is done by selecting some number of random points over the desired interval and summing the function evaluations at these points (see Figure 7) (CHENEY & KINCAID 2004).

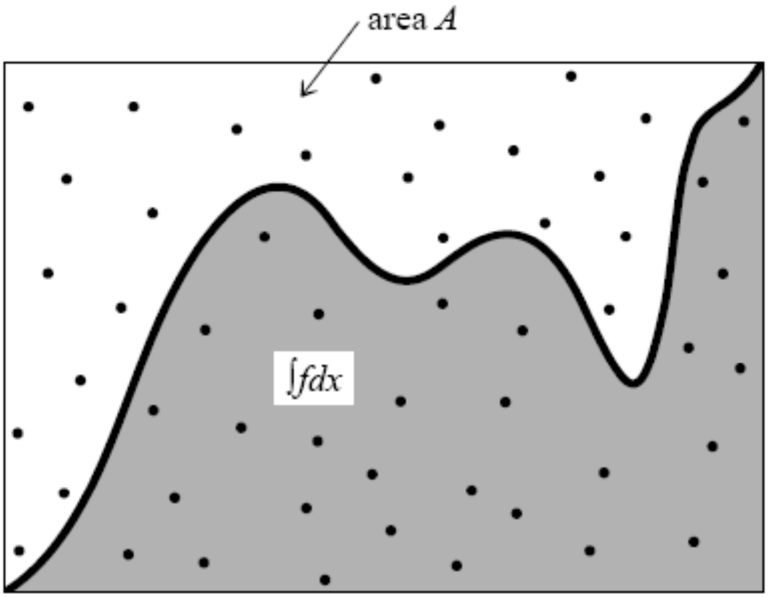


Figure 7: Monte Carlo integration. Random points are chosen within the area A (CHENEY & KINCAID 2004).

The integral of the function f is estimated as the area of A multiplied by the fraction of random points that fall below the curve f (Eq. 5).

$$\int_a^b f(x) \approx \frac{(b-a) * \sum_1^N f(x_n)}{N} \quad (5)$$

This technique can be implemented in multiple dimensions, where the process becomes more useful.

A rigorous evaluation of this technique finds the error to be approximately $\frac{1}{\sqrt{(N)}}$, signifying $O(\frac{1}{\sqrt{n}})$ convergence (ibid.).

We assume that the biomass energy potential p_i is adimensional and is defined as the potential for an hypothetical settlement location of users vi (Eq. 6).

$$Pi := \sum_{j} \left[\left[\frac{Aj}{A} \cdot \frac{(15 - dij)}{15} \right] - Tj \right] * \quad (6)$$

i=1, 2..,N; j≠i

Where:

P_i= biomass energy potential,

V_i= potential settlement,

A_j= Forest cell area,

A= Total forest cell area,

d_{ij}=distance between the potential location of the settlement and afforested areas,

dij ≤ 15km, and

Tj= factor depending on transport and wood extraction cost.

Monte Carlo Integration, as per equation 6, was used to numerically integrate the biomass energy potential according to two criteria: the presence of afforested areas (A_i) within the radius of 15 kilometres, and the distance between the potential location of the settlement and afforested areas (d_{ij}) (see Figure 8).

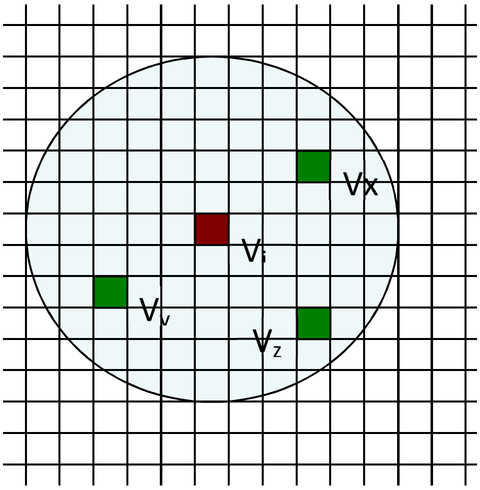


Figure 8: Implementation of the Monte Carlo Integration: V_i= Potential settlement, V_x, V_y,V_z= random forest areas, 15 [km] = Radius (distance between the potential settlement and the forest area)

Table 7 shows the data available for the energy potential estimation:

Energies	**Data**	**Scale/Units**	**Data origin**
Sun	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Local irradiation time	Day	GRASS GIS
	Linke atmospheric turbidity	Dimensionless	GRASS GIS manual
	Ground albedo	Dimensionless	
Wind	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Wind speeds 25 m	m/s	Aeolic Italian Atlas (Atlante eolico italiano)
Geothermal	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Geological Map	1:200.000	Earth Science Department of Cagliari University
Biomass	Land use Map	1:25.000	Region of Sardinia
	Protected areas Natura 2000 Sites	1:10.000	Landscape Plan of Sardinia

Table 7: : Data sources for the energy potential estimation.

For each renewable energy, we have realized the integration of data sets of different origins with different resolution levels. A combination of all data has enabled interdisciplinary analysis procedures and interoperability. Data was obtained from multiple sources and at different scales. We have used vector data in conjunction with raster data. Raster data had a 90 m spatial resolution. The available geological data comprised vector data at 1:200.000 scale. Using these data sets, geothermal energy estimation seems to be suitable at a regional level. Other data is available (e.g. land use maps at 1:25.000 scale and protected area maps at 1:10.000 scale) and is sufficiently accurate for use in studying the eastern metropolitan area of Cagliari.

4.6 Stakeholder survey

After problem definition, the evaluation criteria were selected according to the multi-criteria analysis procedure (cf. MALCZEWSKI 1999). The choice of the criteria was important as it may affect the results of the evaluation process. Therefore, it is important to involve decision-makers in the selection of the criteria. It is also important to note that decisions regarding siting or resource allocation require prioritizing multiple criteria. Thus, with this in mind, different criteria were selected for assessing housing development in general and for settlements with micro-renewables. In order to reduce the complexity of site location problems, a different set of criteria was selected by the author. As a result of time restrictions, it was decided to firstly identify a number of different sets of criteria and then to involve experts for their weighting and prioritization.

Consequently, in the second step, a stakeholder survey was conducted in Italy, Germany and the United Kingdom. The aim was to involve expert groups in the selection of new residential areas with micro-renewable technologies. The survey sought to gain insights into perceptions about new energy efficient settlement development. The survey focused on students and academic planners, regional planners and public authorities. The experts were students, academic planners, regional planners and public authorities from Italy, Germany and the United Kingdom. They comprised of a minimum of 15 people for each category). A total number of 120 questionnaires were completed. Table 8 shows the number of respondents for each category and nationality. Resulting alternatives for housing development with micro-renewable technologies were represented by the six different opinions of experts from the three countries.

The AHP form of expert interviews was chosen because it provided an easy way to ascertain judgments regarding the relative importance experts assigned to pairs of criteria. This was the most important element required to obtain maps which would depict a higher potential of future housing locations. In addition, experts interviewed were allowed to compare knowledge from various disciplines (e.g. urban planning, energy and landscape planning). This will enable improvement of the proposed methodology for future research.

	DE – S. & AP.	DE – RP. & PA.	IT – S. & AP.	IT- RP. & PA.	UK- S. & AP.	UK- RP. & PA.
Total respondents	19	17	19	33	16	16

Table 8: Total respondents: students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.) from each nationality.

In the survey, the personal opinion of the author was included for two reasons. First, the author author evaluates the housing development from an exclusively environmental perspective. Second, the author has prior knowledge of the technical aspects of micro-renewable-technologies, their environmental and landscape impacts, and the planning issues related to their use. The survey allowed stakeholder experts to express their preferences, which were then converted into values. The weighting of a set of criteria in MCDM was achieved using a theory of measurement in a hierarchical structure. This is useful in considering the relative importance of evaluation criteria (SAATY 1980).

This survey consisted of a questionnaire about renewables in residential development. It was distributed in person and by email, with participants returning the completed surveys in the same way (see Annex 1). The expert preferences were quantified using pairwise comparison methods. This method takes the pairwise comparison approach of different criteria as input and determines their relative weights. These weighting factors were calculated using MathCAD engineering calculation software. Consistency Ratios (CR) were used to assess the reliability of the pairwise comparisons (ibid.).

The criteria were divided into factors and constraints (e.g. restricted areas). Maps were generated using a Boolean approach and a Weighted Linear Combination method (WLC) (MALCZEWSKI 1999:312). The Boolean approach is based on a reclassification operation and specified cutoffs (ibid.) The weighted linear combination (WLC), which requires the decision makers to express their preferences, was used to produce suitability raster maps for housing development and micro-renewable preferences considering environmental and landscape impacts. These maps showed the preferred locations of new residential areas with micro-renewable technologies, according to expert stakeholder opinion.

The last step was to identify the optimal sites for new residential areas with micro-renewables by combining the results obtained in the previous steps. Different GIS-map layers were overlaid to obtain the optimal sites for new energy efficient housing development according to energy potential and stakeholder preferences. Raster maps were obtained using the function of the *spatial analyst* available in ArcGIS 9.x, a suite consisting of a group of GIS software products produced by ESRI. The ESRI Spatial Analyst extension enables the user to create raster maps and analyze cell-based raster data. GRASS open source free GIS was another software used for geospatial data management and analysis, image processing, graphic and maps production, spatial modeling, and visualization.

4.6.1 The pairwise comparison method

In the context of the Analytical Hierarchy Process (AHP), SAATY (1980) developed a pairwise comparison method. Pairwise comparison allows environmental and landscape planners to evaluate the contribution of each factor independently, therefore facilitating the decision-making process. Elements in each level are compared in pairs, with respect to their importance to an element in the immediately superior level. Starting at the top of the hierarchy and working down, the pairwise comparisons can be reduced to a number of square matrices as in equation 7:

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{1n} & a_{2n} & \dots & a_{nn} \end{pmatrix} \quad (7)$$

The matrix has reciprocal properties, as illustrated in equation 8:

$$a_{ji} = \frac{1}{a_{ij}} \quad (8)$$

Where:

i, j= 1,…, n

For method effectiveness, the consistency of the pairwise comparison matrix must be calculated (Saaty, 1980). A consistent matrix ensures that for a given decision-maker, if a criterion ***x*** is equally important to another criterion ***y*** (a_{xy} = 1= a_{yx}), and the criterion ***y*** is absolutely more important than a criterion ***w*** (a_{yw} = 9; a_{wy} = 1/9); then criterion ***x*** is absolutely more important than criterion ***w*** (a_{xw} = 9; a_{wx} = 1/9). Unfortunately, the decision-maker is often unable to express consistent preferences in the case of several criteria. However, Saaty's method measures the inconsistency of the pairwise comparison matrix and can be used to define a threshold which should not be exceeded.

Ideally, the comparison matrix (***A***) is fully consistent, the rank(***A***) = 1 and $\lambda = n$ (n = number of criteria). In this case, equation 9 is valid:

$$\boldsymbol{A} \times \boldsymbol{x} = \boldsymbol{n} \times \boldsymbol{x} \qquad (9)$$

Where ***x*** is the *eigenvector* of ***A***

The vector ***x*** represents the weights of interest. When the entries a_{ij} change only slightly, the *eigenvalues* change in a similar manner. Furthermore, the maximum *eigenvalue* (λ_{max}) is closely **greater** to ***n*** while the remaining (possible) *eigenvalues* are close to zero. Thus, is order to find weights, the *eigenvector* which corresponds to the maximum *eigenvalue* (λ_{max}) must be identified.

In order to obtain weights from the calculated eigenvector, the values must be normalized using equation 10 (The weights must sum to a total of 1).

$$w_i := \frac{\sum_{j=1}^{n} (a_{ij})}{n} \qquad (10)$$

for all i =1,2,...,n

Saaty (1980) showed that a relationship exists between the vector weights, w and the pairwise comparison matrix, A, as shown in equation 11.

$$A \cdot w := \lambda_{max} \cdot w \qquad (11)$$

The λ_{max} value is an important validating parameter in AHP and is used as a reference index to screen information by calculating the Consistency Ratio (CR) of the estimated vector. To calculate the CR, the Consistency Index (CI) for each matrix of order n can be obtained from equation 12.

$$CI := \frac{\lambda_{max} - n}{n - 1} \quad (12)$$

Then, the consistence ratio (CR) is calculated as the ratio of consistency index and random consistency index (RI). The RI is the random index representing the consistency of a randomly generated pairwise comparison matrix. It is derived as average random consistency index. CR can be calculated using equation 13:

$$CR := \frac{CI}{RI} \quad (13)$$

Table 9 shows the value of the RI from matrices of order 1 to 10, as suggested by Saaty (1980). If $CR < 0.1$, then the comparisons are sufficiently consistent. $CR \geq 0.1$ indicates inconsistent judgments. The value of RI depends on the number of criteria being compared.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Table 9: Random consistency indices for different number of criteria (n).

The scale used in typical analytic hierarchy studies ranges from 1 (indifference or equal importance) to 9 (extreme preference or absolute importance) and is showed in Table 10.

1- ***Equal*** importance
2- ***Slightly*** more important
3- ***Weakly*** more important
4- ***Weakly to moderately*** more important
5- ***Moderately*** more important
6- ***Moderately to strongly*** more important
7- ***Strongly*** more important
8- ***Greatly*** more important
9- ***Absolutely*** more important

Table 10: Scale of relative importance for pairwise comparison.

The verification of the consistency ratio for the matrices in the questionnaire was conducted with MatCad. Table 11 shows that a total number of 120 questionnaires were completed, with 108 considered in the analysis(consistency ratio <0.1).

	DE – S. & AP.	DE – RP. & PA.	IT – S. & AP.	IT- RP. & PA.	UK- S. & AP.	UK- RP. & PA.	Total
Total respondents	19	17	19	33	16	16	120
Evaluated questionnaires	19	15	16	28	15	15	108

Table 11: Students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.) from each nationality.

In this step of the analysis, the consistency was checked to verify the reliability of the judgment of the decision-maker. The consistency ratio was < 0.10, indicating a reasonable level of consistency in the pairwise comparisons (Malczewski 1999). However, 10 % of the pairwise comparison matrices

(12 questionnaires) were excluded from interpretation because the consistency ratio was ≥0.10.The inconsistency measure was useful for identifying possible errors in judgment in making pairwise comparisons. AHP uses redundant judgments for checking consistency which can exponentially increase the number of judgments. The inconsistency was found almost in completed questionnaire with the same judgment for more than two comparison criteria. In these cases judgments were not correctly differentiated.

4.6.2 Implementation and Analysis

The assumption of Saaty's normal AHP technique is that the weightings derived from hierarchical comparison in normal AHP would be influenced by the preferences given to a particular criterion factor. Once the necessary data was obtained, map layers corresponding to each criterion were created. These layers represented criterion maps. A criterion map indicates the generic nature of the criterion concept and can be considered as an output of GIS based data processing and analysis (Malczewski 1999).

These maps were then be imported into GIS for storing, followed by the allocation of weights to each layer and the allocation of different scores to each attribute using the function of the Spatial analyst. The procedures for generating criterion maps followed the major functionality of GIS. The GIS overlay process was used to combine the factors and constraints, in the form of a Weighting Overlay process. This process produced a suitability map, using equation 14.

$$\text{Suitability Map} = \Sigma\ [\ \text{factor map (cn)} * \text{weight(wn)} * \text{constraint(b0/1)}] \qquad (14)$$

Where:

c_n = standardised raster cell,

w_n = weight derived from AHP pairwise comparison, b0/1 = Boolean map with values 0 or 1, and

n= number of raster cells.

Finally, all the layers were overlaid to compose the constraints map. The resulting map depicted the most, and least, suitable areas for locating housing development with renewable energy. The criteria were divided into continuous suitability factors and constraints (based on binary yes/no restrictions). Given the constraints for locating a new energy efficient settlement, the accuracy in finding the most and least suitable locations was dependent on how the information, from all the constraint layers, was combined to produce a single index of evaluation (EASTMAN 1995). This was realized on the assumption that all layers are of equal importance and carry the same weight. This was achieved by summing the attribute values, by map layer weights, on a cell by cell basis.

The weights for each layer were allocated based on a pairwise comparison for the relative importance of the two layers by rating rows relative to columns. The principle eigenvector of the pairwise matrix was computed to produce a best-fit set of weights (EASTMAN 1995). This calculation was then used to produce suitability maps based on weighted layers.

4.6.3 Procedure of the GIS-based multicriteria analysis

The procedure is outlined in the steps below:

1. Criteria (factors and constraints), relevant for the evaluation of the different perspectives, were identified by the author to build the questionnaire.

2. Two groups of stakeholders, one comprising of students and academic planners and the other of regional environmental planners and public authorities, from Germany, Italy and United Kingdom were presented with the questionnaire.

3. According to Stakeholder preferences, maps that translate the attributes into a measure of suitability were developed using the Analitycal Hierarchy Process (AHP) and the Weighted Linear Combination of factors (WLC).

4. Boolean maps that convert the suitability into true/false (or 0/1) logical statements were developed. They were created for the elimination of those areas that are considered unsuitable for urban development.

In applying the WLC technique, factors were evaluated as fully continuous variables rather than discrete Boolean constraints. For example, if the proximity to roads was considered important in a decision to locating new housing development, a road factor map was developed to express proximity to roads (cf. VOOGD 1983; EASTMAN ET AL. 1993, MALCZEWSKI 1999). The factors were then transformed and assigned their relative weights. Finally, the criteria were combined by means of a weighted linear combination of factors to produce a suitability map (ibid.).

4.6.4 Selecting criteria for urban development

The questionnaire was developed and structured by identifying different criteria that needed to be evaluated in the comparison matrices by experts. Criteria were selected, by the author, to evaluate potential housing sites and to support decisions concerning the location of residential areas. The selection of criteria took into account possible environmental and landscape impacts, as well as the availability of relevant geodata, in order to transform the preferences into spatially explicit representations. To identify the criteria for the development of new settlements, some criteria proposed in the European Spatial Development Perspective (ESDP), in the Regional Landscape Plan of Sardinia and in the development guidelines of the City of Hannover, were extrapolated and synthesized.

From the European Spatial Development Perspective (**ESDP**), drawn up by EU Member States in co-operation with the European Commission, three main criteria were derived:

1. Development of a balanced and polycentric urban system and a new urban-rural relationship,
2. Preservation and development of Natural Heritage, and
3. Conservation and development of cultural heritage (cultural landscapes, cities and towns, natural and historic monuments).

To maintain urban and rural diversity of the EU, the goal is defined as a polycentric settlement structure with a graduated city-ranking. According to the ESDP, this is an essential prerequisite for the balanced and sustainable development of regions. The development of natural resources is based on environmental management and the protection of definite areas (i.e. protected areas and environmentally sensitive areas).

The principle and guidelines of the **Regional Landscape Plan of Sardinia** are deeply rooted in the European Landscape Convention (Florence 2000) and in the ESDP. In regards to housing development, the Plan prescribes the allocation of new development in proximity to existing built-up areas. Protected landscape areas have also been established in order to preserve biodiversity and the cultural heritage.

SImilarly, the **City of Hannover, Germany,** has developed and applied basic guidelines aimed toward to sustainable and environmentally compatible settlement development and an effective urban environment management system (CITY OF HANNOVER 2004).

Residential development in Hannover is based on two principles: minimization of traffic and preservation of the country-side. Urban planning is based on ecological objectives:

- sparing use of building land (high density and good quality accommodations, mixed and multiple uses of areas, space-saving building form and access to facilities),
- priority development in terms of local public transport (e.g. high-density development along tram routes),
- urban greenspace (e.g. conservation and enhancement of the countryside), and
- reducing energy consumption (highest feasible building density, compact development, building orientation for passive uses of solar energy).

The project of Kronsberg, a district of Hannover, is recognized as a model for low energy consumption, ecological soil management, use of environmentally friendly building materials and enhancement of the countryside.

The present work has considered geographical data suitable for urban development at a regional level. Energy potential, and type of land use, requires different socio-economic and environmental analysis (MILLER ET AL. 1998). The identification of criteria is a technical activity based on theory, empirical research and/or common sense. Criteria identification may be conducted via a participatory approach by a group of experts from various disciplines. In this work, the following criteria were selected by the author in order to determine appropriate land for urban expansion:

- proximity to existing urban areas,
- proximity to major roads and train lines,
- distance from protected, environmentally valuable and vulnerable areas,
- proximity to water (sea, lakes and rivers), and
- the slope gradient (see Table 12).

Each criterion should be carefully examined and properly adjusted, depending on local conditions. Physical factors, such as topography, soil and others, should be investigated on the site of proposed urban development. Other factors such as the location, size and accessibility of a site, and its proximity to amenities and services, are also important for the future housing development. They may be considered at a larger-scale scale.

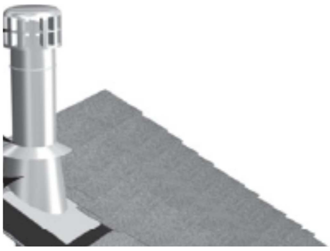
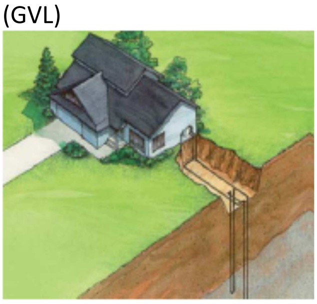
Factor/Criteria	**Description**
Proximity to existing urban areas	The distance to existing urban areas is important because of the significant impact of moving costs,; therefore, locations must be adjacent to built up areas (A G-O YEH 1999)
Proximity to major roads and train lines	Roads are an important factor in housing development as their presence indicates human activity (A G-O YEH 1999).
Distance from environmentally valuable and vulnerable areas or from protected areas	The distance from environmentally significant areas is an important factor to consider, in order to create buffer zones and reduce development impact on those valuable and vulnerable areas (e.g. the Molentargius wetland) (CF. UNESCO, 1974; 1995).
Proximity to water (lakes and rivers)	Amenity value is provided by green spaces and water bodies which improve urban environmental quality (JIM & CHEN WENDY 2006). This factor is relevant in regards to assessing and incorporating it into urban planning and development.
Slope gradient	The slope factor is important because areas exceeding a 10 % gradient are usually unsuitable for residential development (CHAPIN AND KAISER 1978). The optimal areas for residential use are areas with 2-6 % slopes.

Table 12: Criteria for housing development.

4.6.5 Selecting criteria for micro generation

The criteria for the expert survey (Table 13) focused on landscape and environmental impacts as technical factors were included in the potential maps. Criteria identified for new settlements with micro-generators were separated from the criteria selected only for new settlements.

Microgeneration Technology	Factor/Criteria	Type	Description
Solar Panels (SP)  Solar Thermal Collectors (STC) 	Distance from landscape protected areas and other beauty areas	Visual landscape factor	Solar panels and solar thermal collectors can change the visual appearance and character of townscapes, particularly in sensitive landscapes (cultural heritage and protected areas). The impact depends on their design and location (Department for Communities and Local Government: London, 2007: 150).
	Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	Visual landscape factor	
Wind turbines 	Distance from historic/cultural features (historical centre, areas of historical and cultural interests, archeological sites)	Visual landscape factor	A wind turbine can affect views including those of an historic/cultural landscape. Impacts depend on many factors: proximity to neighbors, local terrain, and tree coverage (English Heritage 2008). Building-mounted turbines will generally break the profile of the building and be widely visible (Department for Communities and Local Government: London, 2007: 110).
	Distance from Special Protection Areas (Natura 2000 sites) and others avifaunistic important areas	Environmental factor	Effects are associated with the presence of high concentrations of micro wind turbines on bats and birds, which could result in injury or mortality of bats and/or birds. This may also occur in urban areas. Risks of bird strike can be increased where significant numbers of birds flock (e.g. in close proximity to water bodies and forests) or near Special Protection Areas (SPA), which are important for bird biodiversity protection. The foraging habitat requirements for bats are different. However, potential effects on foraging habitat can be minimized

			by avoiding areas close to woodland and water (Department for Communities and Local Government: London, 2007: 119).
	Distance from other protected areas and of high landscape esthetic	Visual landscape factor	A wind turbine can affect the landscape. It is necessary to pay attention near protected landscape areas, in particular (Department for Communities and Local Government of London, 2007: 110).
Biomass Power Plants (B) 	Distance from historic/cultural features (historical centre, areas of historical and cultural interests, archeological sites)	Visual landscape factor	Combustion gases require an external flue that will usually terminate above the ridge line of the building. If the flue extends 1m or higher above the height of the roof, this can affect views or can alter the profile of the home[4]. This effect should be considered, in particular near protected areas or cultural heritage areas, in terms of views and vistas to and from monuments and other important elements of the historic environment, including gardens and designed landscapes (Department for Communities and Local Government of London 2007: 127).
	Distance from landscape protected areas or other beauty areas	Visual landscape factor	
Geothermal Vertical Loops (GVL) 	Distance from historic/cultural features (historical centre, areas of historical and cultural interests, archeological sites)	Cultural heritage factor	As the installation of ground source heat pumps requires the excavation of trenches or deep boreholes, it is imperative to consider, in advance, whether archaeological remains exist on the development site or in its vicinity. The principal considerations for historic features are: the need to avoid damage to underground archaeology and to find an unobtrusive location for the loops (Department for Communities and Local Government: London, 2007: 103).
	Proximity to drinking water or aquifers	Environmental factor	The garden, or ground available, needs to be suitable for digging a trench, or borehole, and accessible to digging machinery. To install a loop system, vertical bore holes are drilled 50 to 100m in depth and 30-60 cm in breadth. Therefore, it is

[4] It is necessary to have a flue which is specifically designed for wood fuel appliances. Situated on a roughly 45° roof pitch, the flue would have to go 2.3 m above the point where it penetrates through the roof to prevent problems which might include smoking, odors and cold back drafting (Department for Communities and Local Government: London, 2007: 127).

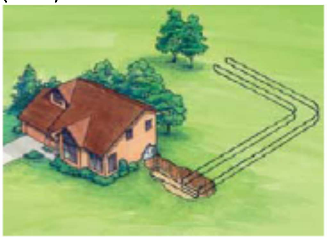
			important to verify the presence of aquifers which, though often difficult, can cause several problems (see the case of Staufen, Germany)[5].
Geothermal Horizontal Loops (GHL) 	Distance from historic/cultural features (historical centre, areas of historical and cultural interests, archeological sites)	Cultural heritage factor	As for the vertical loops, bore works are necessary and attention should be paid to archeological areas (see geothermal vertical loops).
	Distance from flooding areas	Technical factor	This factor concerns damage to the loops caused by a flood, in areas characterized by flooding risk (JENSEN 2010, or.).

Table 13: Criteria for micro renewable technologies.

Criteria were identified according to data availability. Future research improvements may identify and integrate other criteria. In this work, except in the case of the DEM, all other data used to identify expert preferences was regional at the 1:10.000 scale and was provided by the Region of Sardinia. These data sets have a uniform scale and were used to build the Regional Landscape Plan. In this work we have converted vector data (areas, lines and points) into raster data using the GRASS command **v.to.rast**., to obtain continuous maps based on expert preferences. In this step of the process, both software programs, GIS ArcGIS 9.1 and GRASS GIS, were used in a complementary way.

[5] In the historical centre of the city of Staufen im Breisgau (Germany), a project was planned to secure energy production from geothermal energy using vertical loops. While the works were in progress, the excavations penetrated deep artesian aquifers that could infiltrate into the open boreholes. It is highly probable that layers of the Gipskeuper-Formation had been drilled through. The Gipskeuper contains a typical anhydrite that, in contact with water, reacts to gypsum which causes volume extension of about 61 %. Once begun, the swelling process cannot be easily stopped because the process itself opens and closes water paths. The result was a large number of buildings (150) have been affected by cracking and other effects of differential swelling movements beneath the foundations (SASS ET AL. 2009).

Table 14 shows the data used in the stakeholder survey.

Criteria/Factors	Data	Scale/Units	Data origin
Settlements	Build-up areas (Shp)	1:10.000	Landscape Plan of Sardinia
	Main roads and train lines (Shp)	1:10.000	Landscape Plan of Sardinia
	Valuable areas (.shp)	1:10.000	Landscape Plan of Sardinia
	Water (lakes and rivers) (.shp)	1:10.000	Landscape Plan of Sardinia
	Digital Elevation Model	90x90 m	CGIAR Consortium for Spatial Information
Sun	Historical and cultural elements and areas (.shp)	1:10.000	Landscape Plan of Sardinia
	Valuable landscape areas (.shp)	1:10.000	Landscape Plan of Sardinia
Wind	Water, forest, Natura 2000 sites (.shp)	1:10.000	Landscape Plan of Sardinia
	Historical and cultural elements and areas (.shp)	1:10.000	Landscape Plan of Sardinia
	Valuable landscape areas (.shp)	1:10.000	Landscape Plan of Sardinia
Geothermal	Historical and cultural elements and areas (.shp)	1:10.000	Landscape Plan of Sardinia
	Drinking water (Flumendosa's lake) (for vertical loops) (.shp)	1:10.000	Landscape Plan of Sardinia
	Flooding areas (for horizontal loops) (.shp)	1:10.000	PAI Region of Sardinia
Biomass	Historical and cultural elements and areas (.shp)	1:10.000	Landscape Plan of Sardinia
	Valuable landscape areas (.shp)	1:10.000	Landscape Plan of Sardinia

Table 14: Details of the basis data used for the suitability maps.

Restriction areas were applied after prioritizing criteria by expert preference and were comprised of built-up areas, water (lakes and rivers) and areas characterized by hydrogeological instability. The data was obtained from different sources and at different scales. Not all regional data has the same level of accuracy. The regional plan for hydrogeological instability (PAI, "Piano di assetto idrogeologico") identifies hazard and dangerous areas for human activities, including building, in a four-point scale. The study areas with hazard/risk evaluation scores of 3 or 4 were excluded.

Table 15 shows the data for the restrictions areas:

Constraints	**Data**	**Scale/Units**	**Data origin**
Built-up areas	Shape-File	1:25.000	Landscape Plan of Sardinia
Water surfaces	Shape-File	1:25.000	Landscape Plan of Sardinia
Areas with hydro-geological instability	Shape-File	1:10.000	Plan for hydrogeological instability (PAI, "Piano di assetto idrogeologico")

Table 15: Details of the basis data used for the constraint maps.

5. Results: Methods for estimating spatial distribution of energy potential and application in the Cagliari area

5.1 The eastern metropolitan area of Cagliari as case study

The eastern metropolitan area of Cagliari in the south of Sardinia (see Figure 9**)** encompasses the municipalities of ***Cagliari, Selargius, Monserrato, Quartu Sant'Elena, Quartucciu, Settimo San Pietro, Sinnai e Maracalagonis*** (Figure 10). It has an area of 591 km^2 and, in 2009, had a population of 322.392 inhabitants (ISTAT DATA 2010, WWW). Cagliari is the capital of Sardinia, situated on the southern shore of the island at the "Gulf of the Angeles" (*Golfo degli Angeli*).

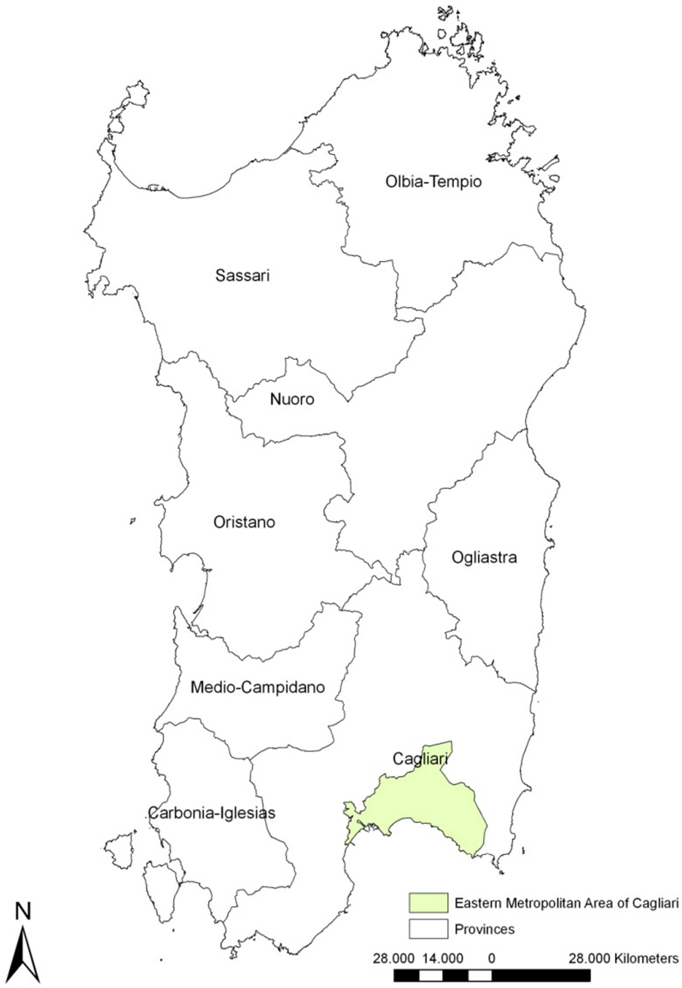


Figure 9: The region of Sardinia (scale: 1:250.000)

The metropolitan area encompasses the surrounding suburban and rural area and is embedded in the Cagliari province. It is surrounded by the mountain ranges of the *Sette Fratelli* in the east and *Capoterra* in the west, and stretches northward into the plain of *Campidano*.

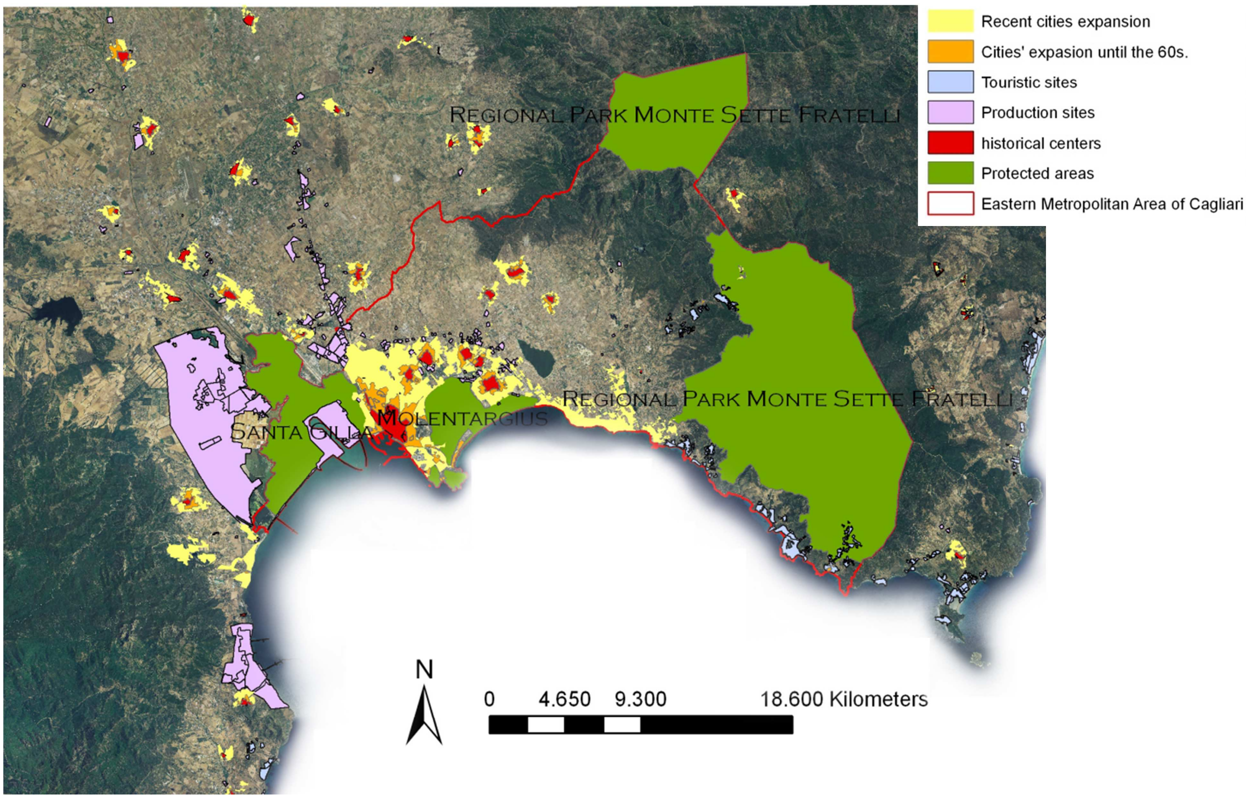


Figure 10: The Eastern Metropolitan Area of Cagliari, Sardinia (scale: 1:250.000).

This area is chosen for the case study for its favorable conditions for the application of a renewable energy mix. Land demand for settlements, traffic infrastructure and tourism development, in the area has risen from the end of the 1960's (see Figure 11). Some of the key challenges for landscape planning in the Cagliari eastern metropolitan area are: to propose energy efficient urban development to fulfill the growing demand for housing and infrastructure, to exploit opportunities for renewable and decentralized micro energy production, and to respect the requirements for sustaining valuable cultural and natural resources and the continued provision ecosystem goods and services. Landscape planning can build upon recent efforts for comprehensive landscape assessment and strategy development, in particular in regards to the recently published Sardinian Landscape Plan ("Piano Paesaggistico Regionale" 2006). It was the first region in Italy which responded to the European Landscape Convention (COUNCIL OF EUROPE, 2000) and the national landscape legislation ("Codice Urbani" 2004). The study area's ecologically most relevant site, the Molentargius wetlands, which are recognized by are the the Ramsar convention and Natura 2000, are threatened by the growth of the urbanization. The area is nationally protected as a *Parchi Regionali* (cf. FEDERPARCHI 2009), a conservation designation that covers areas with special natural, environmental and cultural significance value for the local population (cf. MINISTERO DELL´AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE 2007, www).

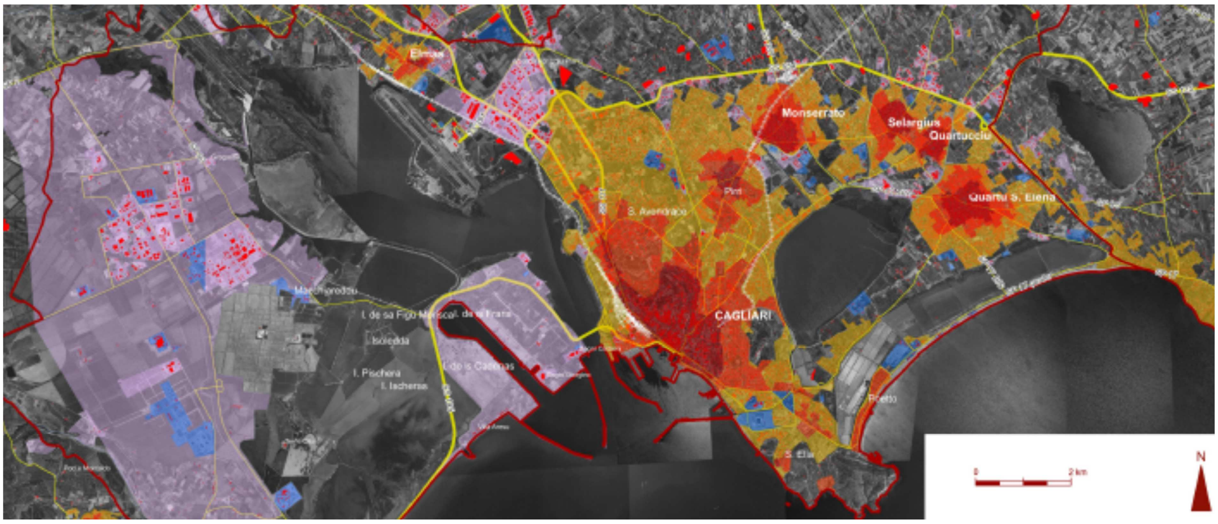


Figure 11: Increasing demands for settlement in Cagliari (deep red = ancient centre, orange = extensions until the end of 1950s, yellow = urban enlargement since 1960, magenta = trade and industry, blue = areas of touristic importance).

5.2 Landscape planning in Sardinia

Landscape planning in the region of Sardinia is based on the protection of landscape and recovery of identity values, which are characterized by urban, development, production, historical and cultural sites. The Regional Landscape Plan of Sardinia ("Piano Paesaggistico Regionale"- P.P.R.) has paved the way for the application of the principles contained in the European Landscape Convention (ELC). According to the P.P.R., the landscape plan plays a crucial role in planning by defining strategic objectives, methods and the contents of planning at sub-regional and local levels.

The most innovative aspect of the landscape plan, when compared to previous regional planning, is the management and control of land transformation processes: the plan assumes landscape protection, based on the preservation of environmental and cultural values in the landscape, which are not modified by human activities or urbanization, as its main objective. This trend, expressed through the principle of landscape protection, is combined with other principles such as the management and development of landscapes through projects, at all scales of intervention, in order to improve environmental quality in degraded landscapes and to reinforce the sense of community identity. Furthermore, all undeveloped coastal areas are required to remain intact. This is largely in reaction to the rapid increase in development along the coast since the 1960s which sought to exploit the coastal resources for tourist use, locating new development without planning control. (cf. MANCA, 2009).

The landscape plan introduced a further definition, of the "coastal zone". It was defined as a set of strategic resources of relevance, where environmental, cultural and human factors are closely interrelated. Under the PPR, new coastal development is to be planned near existing urban centers in order to reducing the urban pressure. To reduce urban sprawl, there are strict limitations in building size, in relation to the property area, and agro-forestry and pastoral activities in the country-side. The PPR also identifies strategies for restoring amenity in areas compromised by abandonment, land use incompatibility with character, and the indiscriminate use of resources, for example. The Plan proposes to apply the principle of minimum land use for irreversible transformation resulting from new developments. In addition, it prohibits development within 300 meters of the shore line. The principle, followed by the regional plan, is the compact city, where the priority is to re-utilize (e.g. utilizing abandoned spaces, land use conversions and so on).

The structure of the Regional landscape plan of Sardinia

There are three ways of perceiving landscape and defining the elements that form its identity: environment, history and culture, and settlements. These three readings allowed identification and regulation of the assets and components of the landscape belonging to each of the categories chosen. Within the landscape, each element is part of a given context and, within that context, it enters into a particular relationship with the elements belonging to other categories (MANCA 2009). It is for this reason that landscape analysis is completed by identifying 27 landscape domains, for which a detailed analysis is conducted. Every domain contains a project idea for future transformations, made explicit by several directions for the local community, for example in municipalities through land use plans, to keep (BIGGIO 2009). The directions constitute general objectives, and purposefully remain generic, so that they maintain the flexibility needed for subordinate planning instruments to identify the most appropriate strategy to pursue such objectives (ibid.).

Landscape domains/areas

The landscape area "Gulf of Cagliari" ("Golfo di Cagliari") and 27 "Eastern Gulf of Cagliari" ("Golfo orientale di Cagliari") cover the case study area. The directions given for both landscape areas are: to localize new residential areas in proximity to built-up areas, and to avoid settlement development on coastal zones. This direction is connected to the purpose of restoring historical centers and containing city expansions. The regional landscape plan is environment-oriented and seeks to connect and preserve sensitive areas, such as the Molentargius wetland, S.Gilla, the Poetto Beach and the Monte Sette-Fratelli Regional Park. The presence of two wetlands of international and community importance within the metropolitan area of Cagliari, where a quarter of the total inhabitants of Sardinia are concentrated, poses particular difficulties for the management of coastal wetlands and the revision of urban and landscape planning (SCHRENK 2009). As both wetlands contribute to the generation of eco-systems, they have a significant impact on the micro-climate and affect the quality of life of the urban areas in their vicinity (ZOPPI 2009)

The Molentargius wetland includes different habitats: freshwater basins (Bellarosa Minore and Perdalonga), salt water basins (Bellarosa Maggiore and salt ponds), coastal areas (Poetto beach), and a flat characterized by prevailing aridity (Is Arenas) (see Figure 12). The Molentargius saline filled with salt water is home for various halophytes. While Poetto beach is a major habitat for large number of waterfowl, the Bellarosa basin contains fresh and brackish water separated by an ecological filtration system and provides important habitat for flamingos, among others.. Aside from these well known and clearly defined wildlife habitats, green and forest areas with a variety of domestic flora species can be found throughout the case study area.

Despite the restrictive laws in effect, many illegal buildings have surfaced, reducing the desire to preserve the area. Notably, municipal administrations did not take the initiative to enforce conservation rules, instead acting to change the natural environmental vocation of the area. In the area of Is Arena, an area characterized by fields of forage, eucalyptus, olive threes, vineyards, tree lines and brush vegetation., several instances of illegal buildings, abandoned quarries, and illegal dumps can be identified.

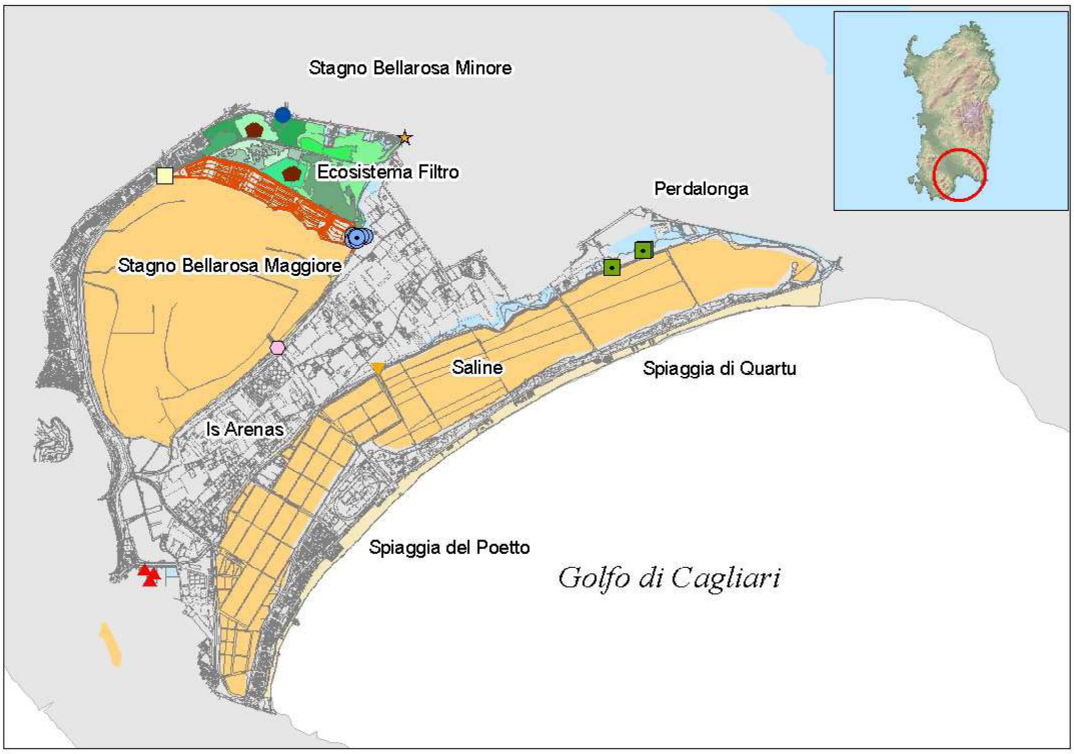


Figure 12: Molentargius wetland

5.3 Solar energy potential estimation in the eastern metropolitan area of Cagliari

To calculate the preliminary solar energy potential for the eastern metropolitan area of Cagliari the following input parameters were used:

1. *Elevin*= DEM raster from SRTM90 DEM (CGIAR Consortium for Spatial Information) with a primary resolution of 3 arc seconds (90 m).
2. Slopein= slope raster map generated from the 90 DEM using the *plugin* **r.slope.aspect**.
3. Aspin= aspect raster map generated from the 90 DEM using the *plugin* **r.slope.aspect**.
4. Latitude= parameter directly estimated from the raster map
5. Albedo= constant parameter set equal to 0.2 (default value)
6. Linke turbidity= constant parameter set equal to 3.0 (default value)

Digital Elevation Model (DEM)

A Digital Elevation Model with 90 m resolution, as digital representation of the ground surface topography, was used as input to create the slope and the aspect maps (see Figure 13).

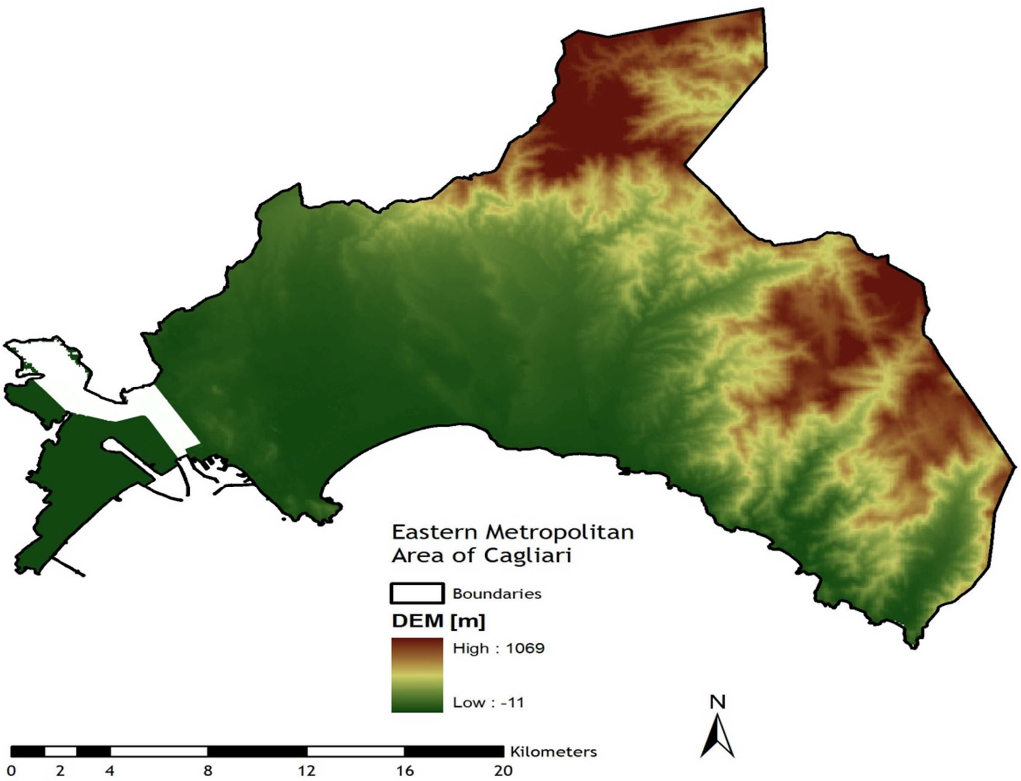


Figure 13: Digital Elevation Model 90 m resolution, scale 1: 250.000.

Aspect: Azimut-angle of the terrain (*aspin*)

The parameter *aspin* describes the angle at which a terrain surface differs from the southerly direction. This angle is called Azimut. For example, if the Azimut is 0°, this means an exact southern alignment of the surface. With an Azimut of -90°, the terrain would be aligned to the east, thus, an Azimut of +90° indicates a western alignment. At -45° or +45° theAzimut is directed south-easterly or south-westerly (GROßKOPF O.J., HEINDL INTERNET AG 2009). Figure 14 shows the aspect for the eastern metropolitan area of Cagliari.

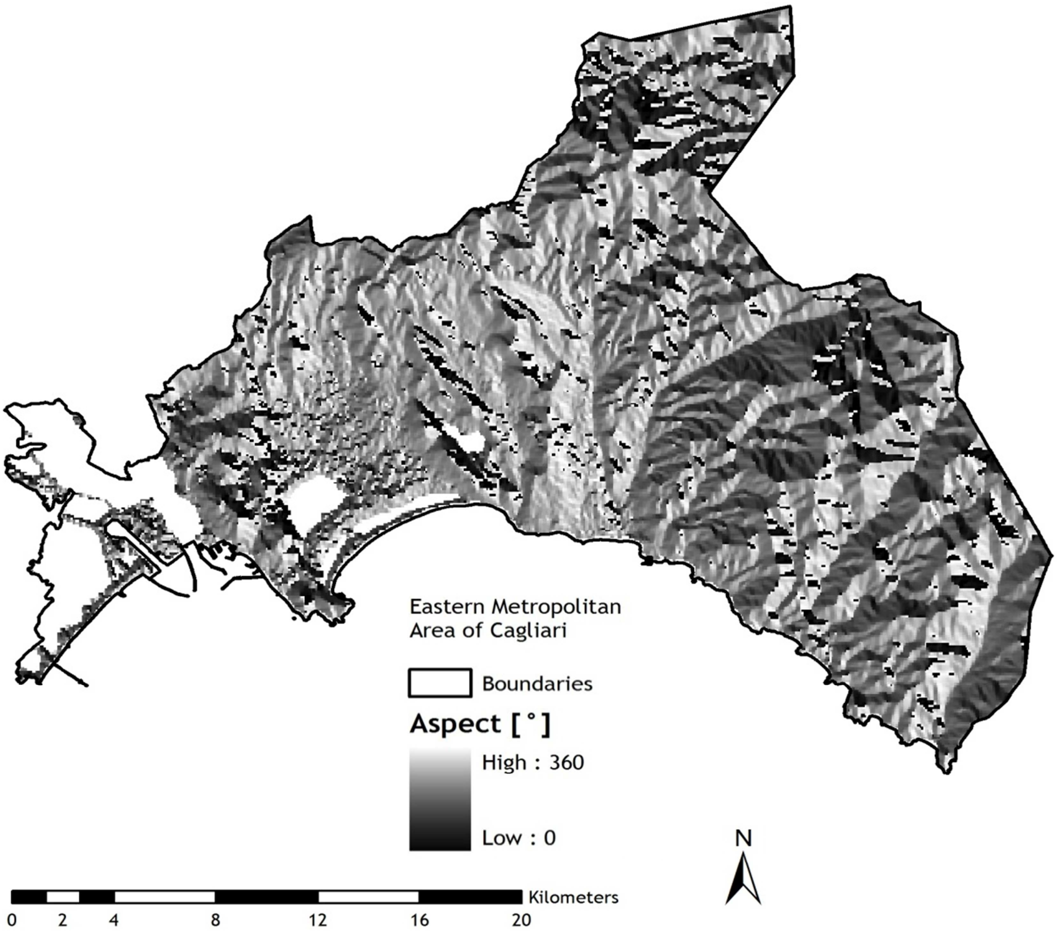


Figure 14: Aspect or Azimuth-angle of the terrain, scale 1: 250.000.

Slope of the terrain (*slopein*)

The parameter *slopein* expresses the slope of terrain surfaces. The slope describes the angle between the terrain surface and the horizontal (GROẞKOPF O.J.2009,). For example, each terrain surface can be either horizontal or in a certain slope angle. This way it faces directly to the sun and is able to gather the biggest possible amount of solar radiation. 'The greatest possible energy output can be achieved when the surface is aligned in right angle to solar irradiation' (cf. GROẞKOPF O.J. 2009).

The figure 15 shows the slope for the eastern metropolitan area of Cagliari.

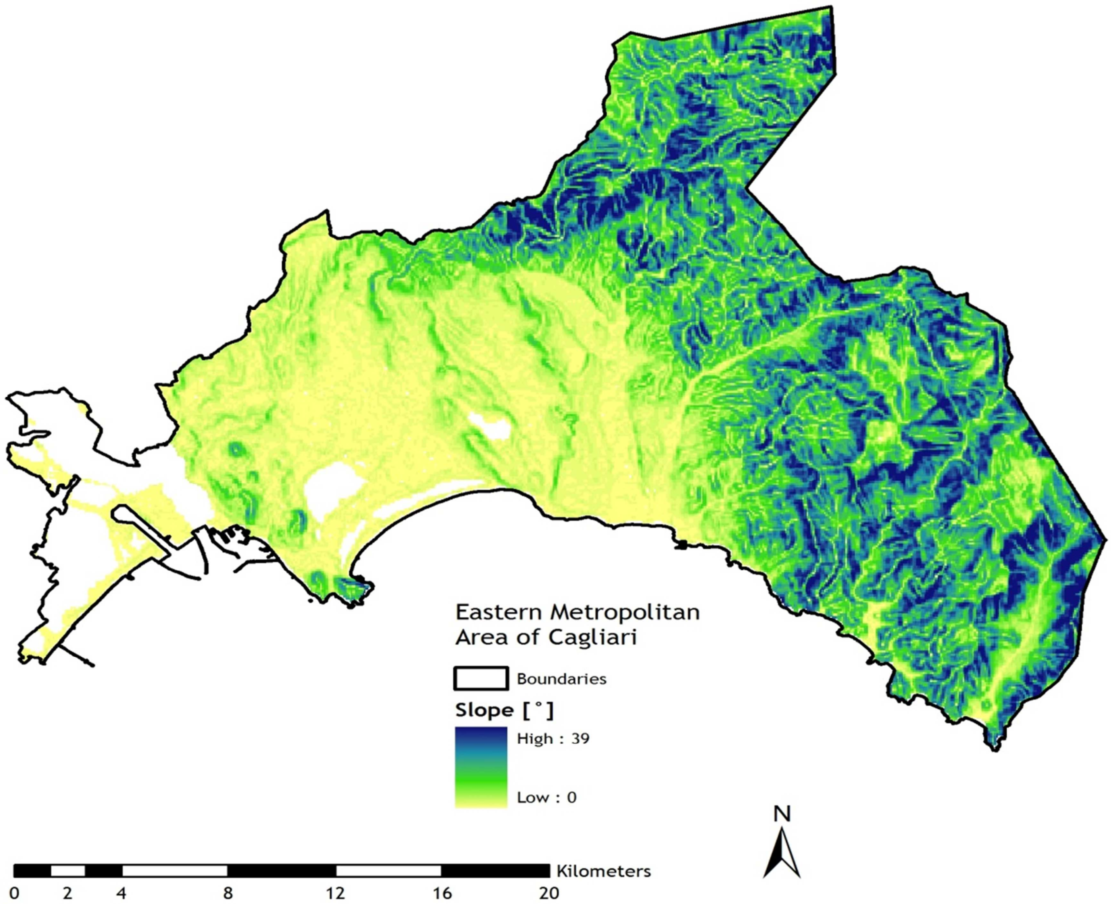


Figure 15: Slope of the terrain, scale 1: 250.000.

Both Azimut and slope depend on geographical latitude. There is a different solar altitude, depending on the latitude, and therefore solar radiation faces a different angle on terrain surfaces. Azimut and slope need to be chosen regarding this phenomenon to achieve the greatest possible capacity.

Landuse in the eastern metropolitan area of Cagliari

The prevalent land use of the eastern metropolitan area of Cagliari is characterised by rural areas. However, the suburban sprawl differs from urbanized districts as it contains a large allotment of agriculture land usage (around 46.72%). Other land uses, such as residential, commercial and industrial, cover about 40 % of the area. Forest areas cover a mere 5.39%, with the remaining part of the surface area distributed between green areas (0.59%), wetlands (0.65%), areas with sparse vegetation (5.83%) and water surface (0.64%).

The Figure 16 shows the land use in the case study area.

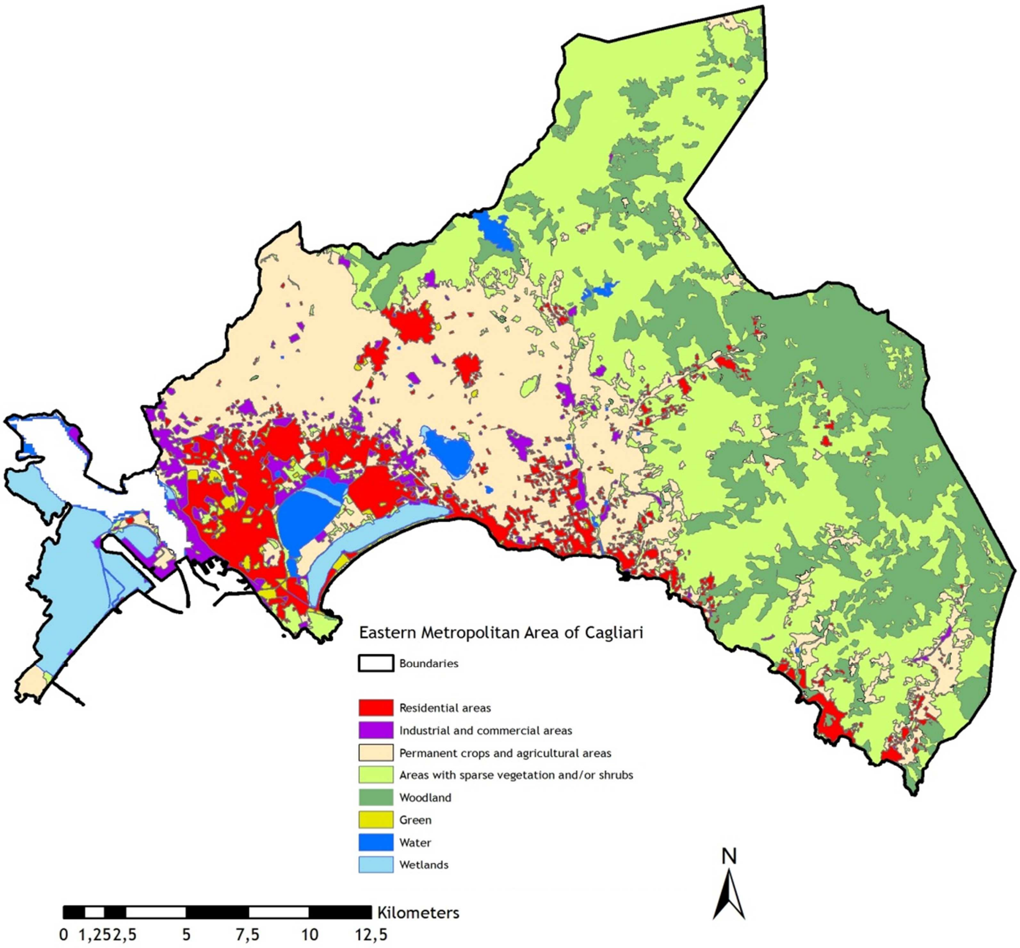


Figure 16: Land use, scale 1: 250.000.

Reflectance of the earth's surface (albedo)

The reflectance of surfaces is called albedo. It describes the relationship between reflected and absorbed solar radiation. This parameter is important in calculating the irradiance of the sun on flat surfaces as energy potential of sun rays depends on how many rays are absorbed, reflected or transmitted. Given that different surfaces rather land use have a different reflectance, the albedo value varies in the case study area. For example, dry, black soil has an amount of reflection of 14 % (albedo=0,14), conversely, a water expanse has a reflection of 5-15 % (albedo=0,05-0,15). Thus, an average value valid for rural city areas, an albedo of 0,2 is presumed, for this study (SÚRI & HOFIERKA 2002).

Linke turbidity (linkein)

The turbidity of an atmosphere depends on various factors such as the dispersion of molecules in the air, absorption of steam, ozone and carbon dioxide and the dispersion and absorption of aerosols (dust and water drops) (OBERTHIER 2009, WWW). The factor of turbidity, defined by F. Linke, is considered as a dimension for the turbidity of an atmosphere. It specifies the 'amount of the clear, dry atmospheres only consisting of air molecules, which would cause –on account of their diffuse reflection- the same degradation of solar radiation as the actual atmosphere with its misting components located above a city' (BLÜTHGEN & WEISCHET 1980: 176). This indicates that the factor of turbidity stands for the amount, with which the real, actual, atmosphere is misted in comparison with a clear atmosphere. The factor of turbidity also varies –like the albedo- with great intensity within a region. The value of an absolute clear atmosphere is 1,0 (SÚRI & HOFIERKA 2002). Polar air has the lowest factor of turbidity, at 1,9, while tropic air has the highest turbidity factor, at 3,6 (OBERTHIER 2009, WWW). Big cities can achieve a turbidity factor up to 4,4 because of the high emission rate (smog) (ibid.). An average value for the Linke turbidity is 3,0 which is close to the annual average of rural city areas (SÚRI & HOFIERKA 2002).

Data processing

The cell resolution is 3 arcsec or 90m both. The elevation is measured within an accuracy of 3m. The latitude was computed directly from the DEM raster, while the albedo and the linke turbidity were believed constant over the entire region, as a first approximation. The clear sky indexes were not available. The final database consists of raster maps representing the monthly averages and the annual average of global irradiation daily sums estimated for horizontal surfaces. The output units are [Wh/m^2/day]. The influence of terrain shadowing was taken into account by setting the -*s* flag. The sum of daily raster maps of global irradiation provided the cumulated maps for every month, and finally, for the whole year; by dividing the month duration the monthly average can be obtained (see Figure 17). The daily maps are calculated by the sum of reflected, diffuse and beam radiation using the function **r.mapcalc**. In generating raster maps, the most critical issue is the linke turbidity factor as its estimation is still prone to significant uncertainty and clear-sky indexes were not available. In this case, the solar irradiation for the eastern metropolitan area of Cagliari was overestimated, as it did not take into account cloud coverage. Furthermore, the Linke turbidity index in this first approximation was considered constant; however, it varies over the region.

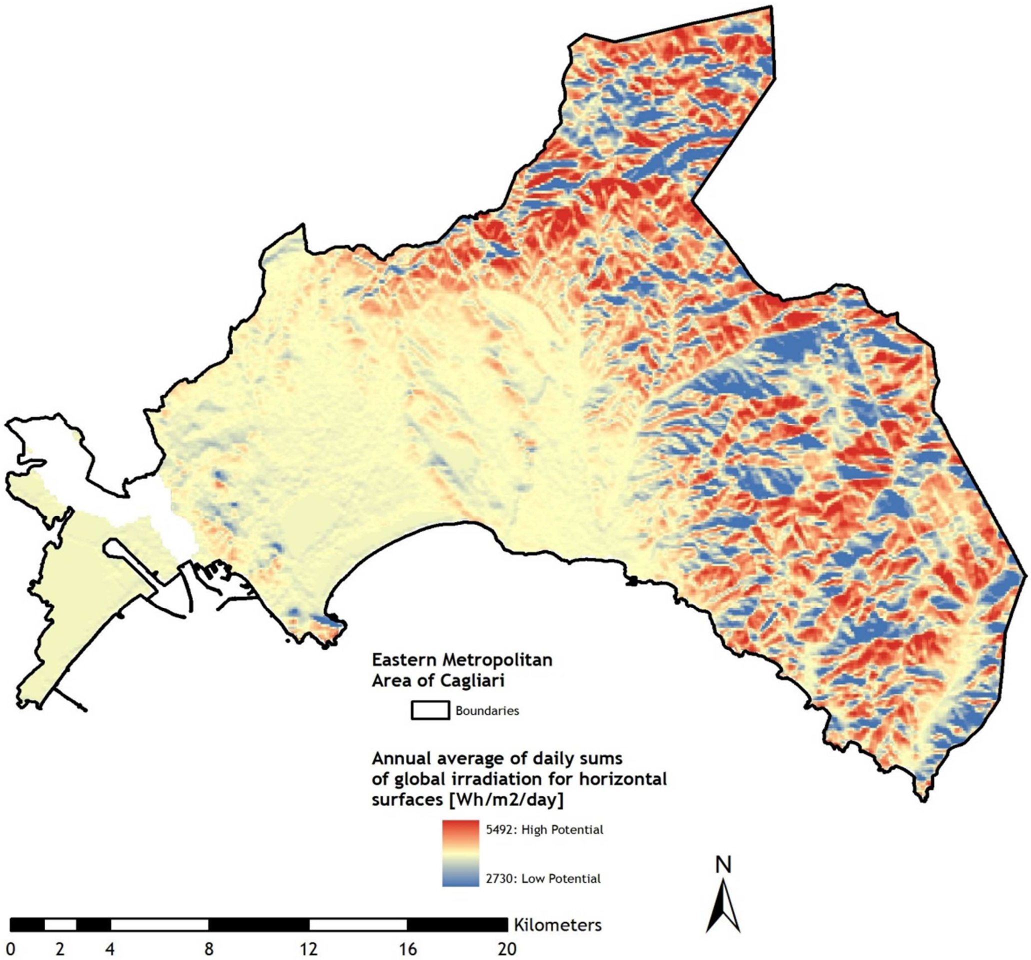


Figure 17: Annual average of daily sums of global irradiation for horizontal surfaces [Wh/m^2/day] for clear sky conditions, scale 1: 250.000.

Values of the monthly irradiation for Cagliari city, derived from the Photovoltaic Geographical Information System- Interactive Maps (JRC 2009, WWW) were used to validate the data and to obtain the final distribution from the spatial distribution of the preliminary solar radiation potential.

Furthermore, the **r.univar** plugin was used to calculate the mean value of the map. Using this value, and data from the ***PVGIS*** database, we can modify the calculated values and to obtain the final map. In so doing, the locally specific factors to the south of Sardinia, such as the different impacts of the linke turbidity and indexes for clear sky, were accounted for. Finally, the output raster map was a raster map of annual average daily sums of global irradiation for horizontal surfaces [Wh/m^2/day] (see Figure 18).

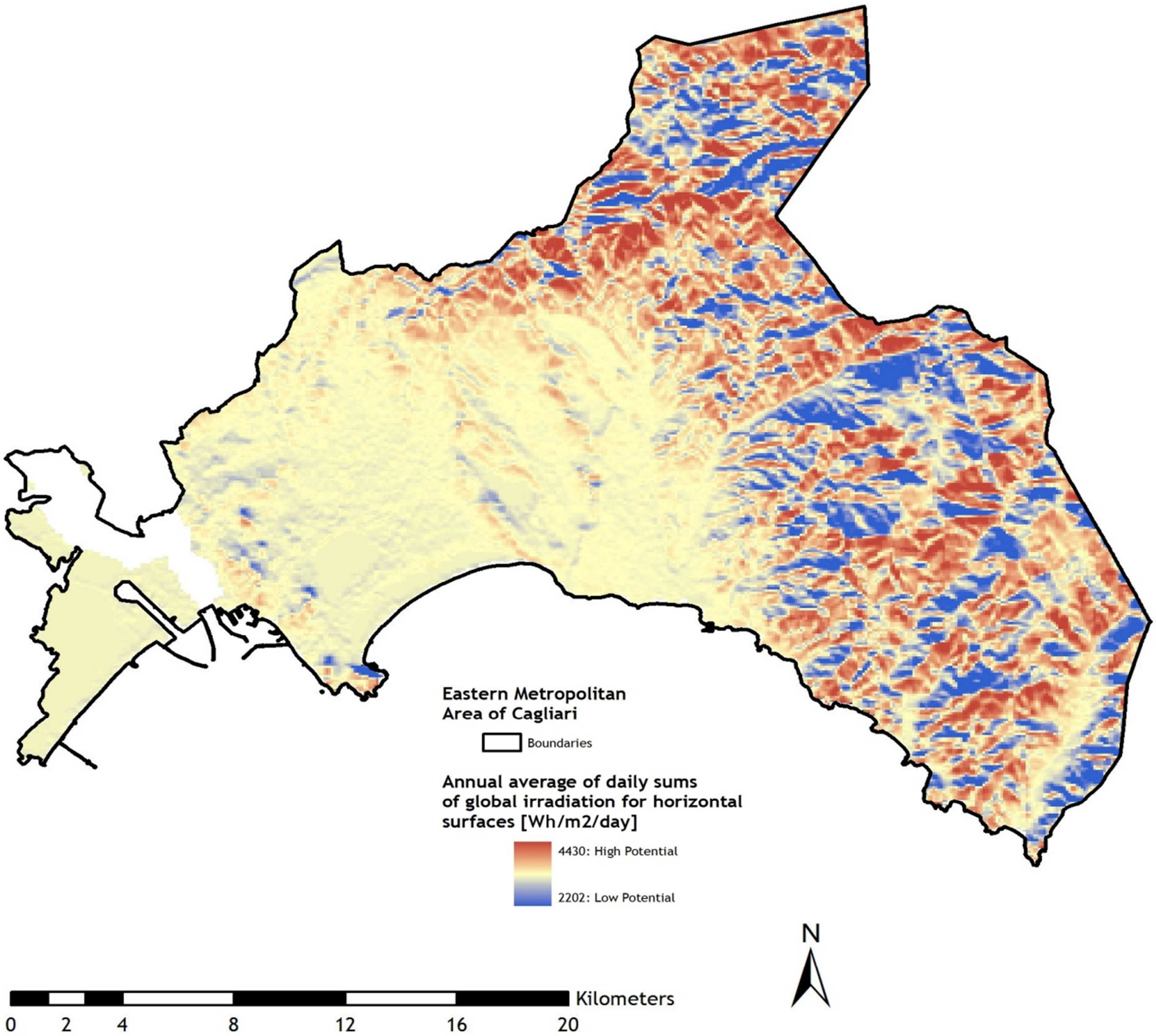


Figure 18: Annual average of daily sums of global irradiation for horizontal surfaces [Wh/m^2/day], scale 1: 250.000.

5.4 Wind energy potential estimation in the eastern metropolitan area of Cagliari

An equation (COUNIHAN 1975; TOUMA 1977) was used to calculate wind speeds at 25m on a Digital Elevation Model; the resulting output was wind speed at 25 m rescaled on a DEM (90). The final wind raster map was obtained from this data for a wind speed at 10 m height above ground level. It was assumed that for each cell in 1-km raster resolution, these factors remain constant.

In this work, the following input parameters were used to calculate wind energy potential for the Eastern Metropolitan Area of Cagliari:

- DEM raster from SRTM90 DEM (CGIAR Consortium for Spatial Information) with a primary resolution of 3 arc seconds (90 m),
- DEM raster 1km (calculated with GRASS GIS), and
- Wind average speeds at 25 m height above ground level, in reference to a grid of approx. 1x1km obtained from the Italian Wind Atlas (2002).

Processing data

The initial 90m DEM was corrected to avoid negative aids above sea level. All values less than 1 were substituted by 1 m using the **r.map calc** *plug-in* from the GRASS software. To generate the 1-km DEM from the 90 m DEM, the **r. neighbors** *plug-in* was used to calculate the average values for 1 km. Without interpolation, wind speed values were downscaled to 90 m simply repeating values in each cell. This action was performed with the plug-in **r.resample.** A light smooting function **r.resamp.rst** was applied to 90 m DEM to avoid artifacts at 1 km original cell boundaries. Finally the equation was applied to obtain a final average wind speed raster map with a resolution of 90 m (see Figure 19).

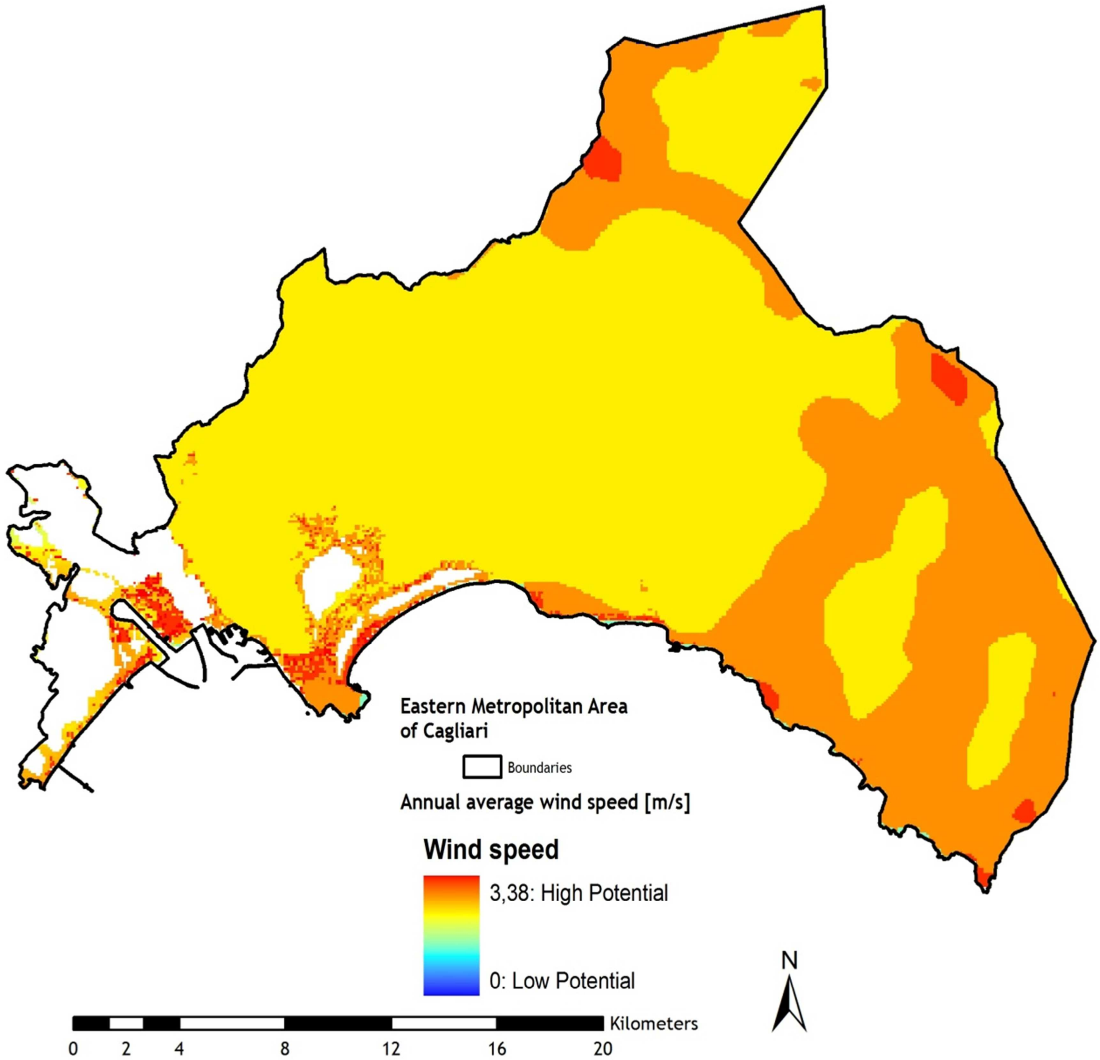


Figure 19: Wind speeds [m/s], scale 1: 250.000

5.5 Geothermal energy potential in the eastern metropolitan area of Cagliari

Energy potential map for vertical loops

To obtain the specific heat extraction values, at a depth of 100 m, the soil was divided intwo homogeneous layers of unconsolidated and solid rocks. Comprehensive data was unavailable for unconsolidated rocks at the detail of planning requirements; therefore the thickness is, at times, only a rough estimate. The data available for solid rock was more accurate. The information regarding ground water flow was not considered (in accordance with VDI 3640 German directive). In lower groundwater levels, the groundwater movement could not be quantified. For this reason, the forecasts of the specific heat extraction values were based on the heat conductivity of the subsurface (LEITFADEN FÜR OBERFLÄCHENNAHE ERDWÄRMEANLAGEN - LANDESAMT FÜR NATUR UND UMWELT DES LANDES SCHLESWIG-HOLSTEIN). Depending on the heat conductivity of the subsurface, the full number of running hours, and the type of probe, the specific heat extraction values for plants up to a heat output of 30 kW have been calculated (VDI 4640). The VDI directive serves as a basis for the dimensioning of ground coupled heat pumps.

The conditions of the VDI directive are:

- Heat extraction only.
- The length of individual borehole heat exchangers must be between 40m and 100m.
- The shortest distance between two borehole heat exchangers must be:
  - At least 5 m for borehole heat exchanger lengths of 40 to 50 m.
  - At least 6 m for borehole heat exchanger lengths of > 50 m to 100 m.
- Double U-pipes with coaxial probes, with a minimum diameter of 60 mm, are used as borehole heat exchangers.

Processing data

The terrain height at each grid point was appended by the use of the height grid DEM 90. To affiliate the heat extraction capacity of loose rocks, the geological map of the region of Sardinia was used as the input (see Figure 20). This map was consulted to evaluate the specific heat extraction capacities, as it describes the different types of rocks. This was subsequently combined with values from literature, with regard to specific heat conductivity.

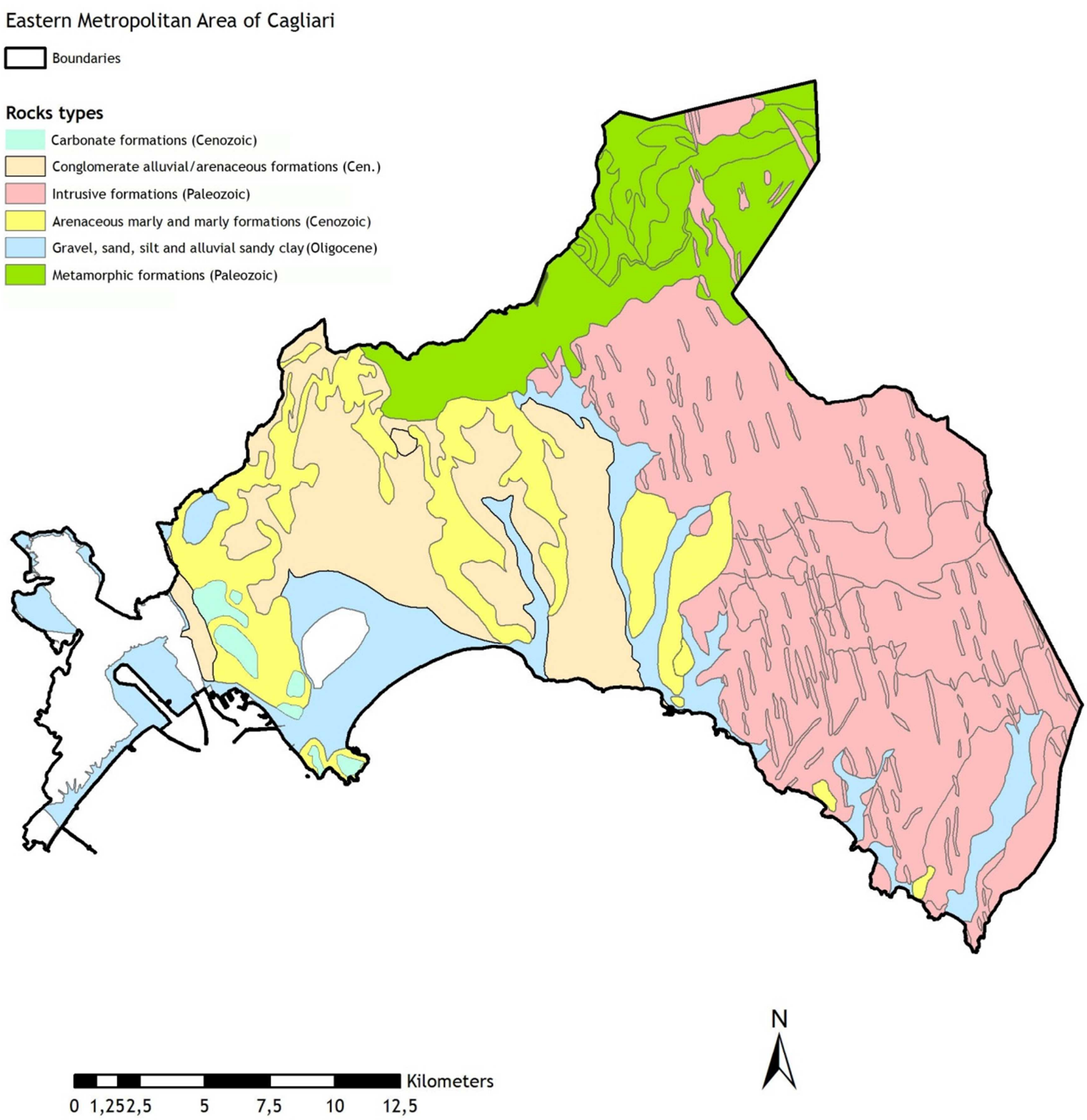


Figure 20: Geological map, scale 1: 250.000.

The VDI 4640 and the Swiss standard SIA contain indications of individual rock types. These values of heat conductivity represent clay / silt at 1.7 (VDI) and sand at 2.4 (VDI), or at 1,4-2,5 (SIA) for fine sand. According to the equation of Kaltschmitt (1999), specific heat extraction capacity reached from 20 to 52 [W/(m*K)]. Since the Tertiary was frequently dominated by sand, an average value of sand, and clay / silt, of 38 [W/(m*K)] was designated. Based on the resulting structure of the subsurface layers, the specific heat extraction capacity of the probe was calculated. The result was a raster map of the specific heat extraction capacities (see Figure 21). These were classified into three categories:

- Category 1: < 20 [W/m] = **unsuitable for economic reasons**
- Category 2: approximately ≥20 and < 50 [W/m)] = **suitable**
- Category 3: approximately ≥ 50 [W/m)] = **very suitable**

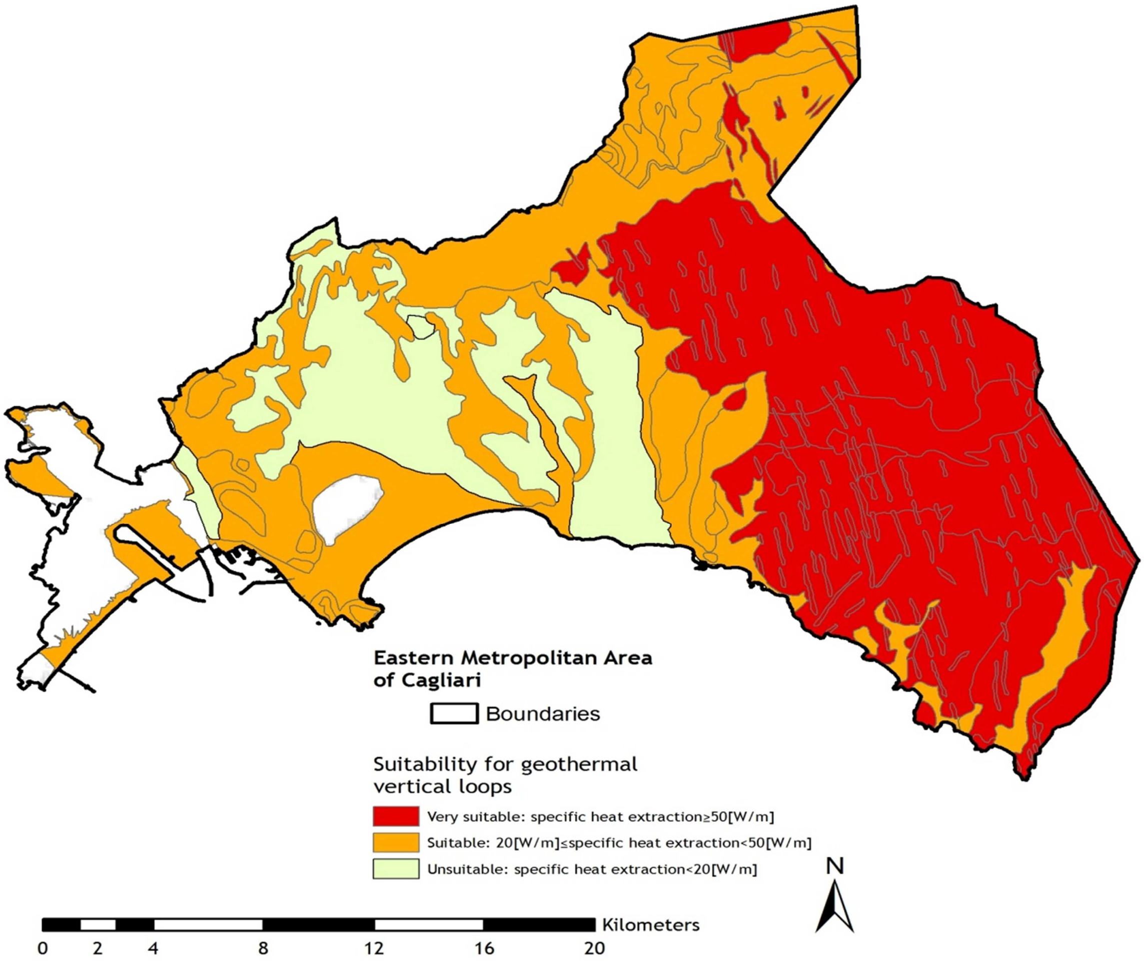


Figure 21: Geothermal potential estimation for vertical loops, scale 1: 250.000.
The unsuitable areas depicted are unsuitable for economic reasons.

Energy potential map for borehole heat exchangers (horizontal loops)

The geological, irrigation and land use maps were considered in determining the suitable and unsuitable areas for horizontal loops installation. The geological map was consulted to evaluate the specific heat extraction capacities for vertical loops. The irrigation map was used in evaluating the presence of soil up to 1.3 m in depth. It took into account the land classification proposed in a soil survey commissioned by the Region of Sardinia in 1986 to determine the suitability for irrigation for agriculture use (ARU ET AL. 1986). The land use map aided the selection of agricultural areas and was used, in combination with the irrigation map, to show arable and not arable areas for the region. Soil suitable for agriculture makes up a very small part of the land area of Sardinia, however is suitable almost in the case study area. It was possible to obtain a qualitative potential estimation for the use of horizontal loops despite the variety of soil conditions (e.g. evapotraspiration) and characteristics (e.g. presence of aquifers), soil types, and the lack of quantitative data of all factors (ARU ET AL. 1991). Further specific onsite studies and local analyses are required for increased precision in the planning and design of horizontal loops.

The Figure 22 shows the suitability for geothermal energy using horizontal loops.

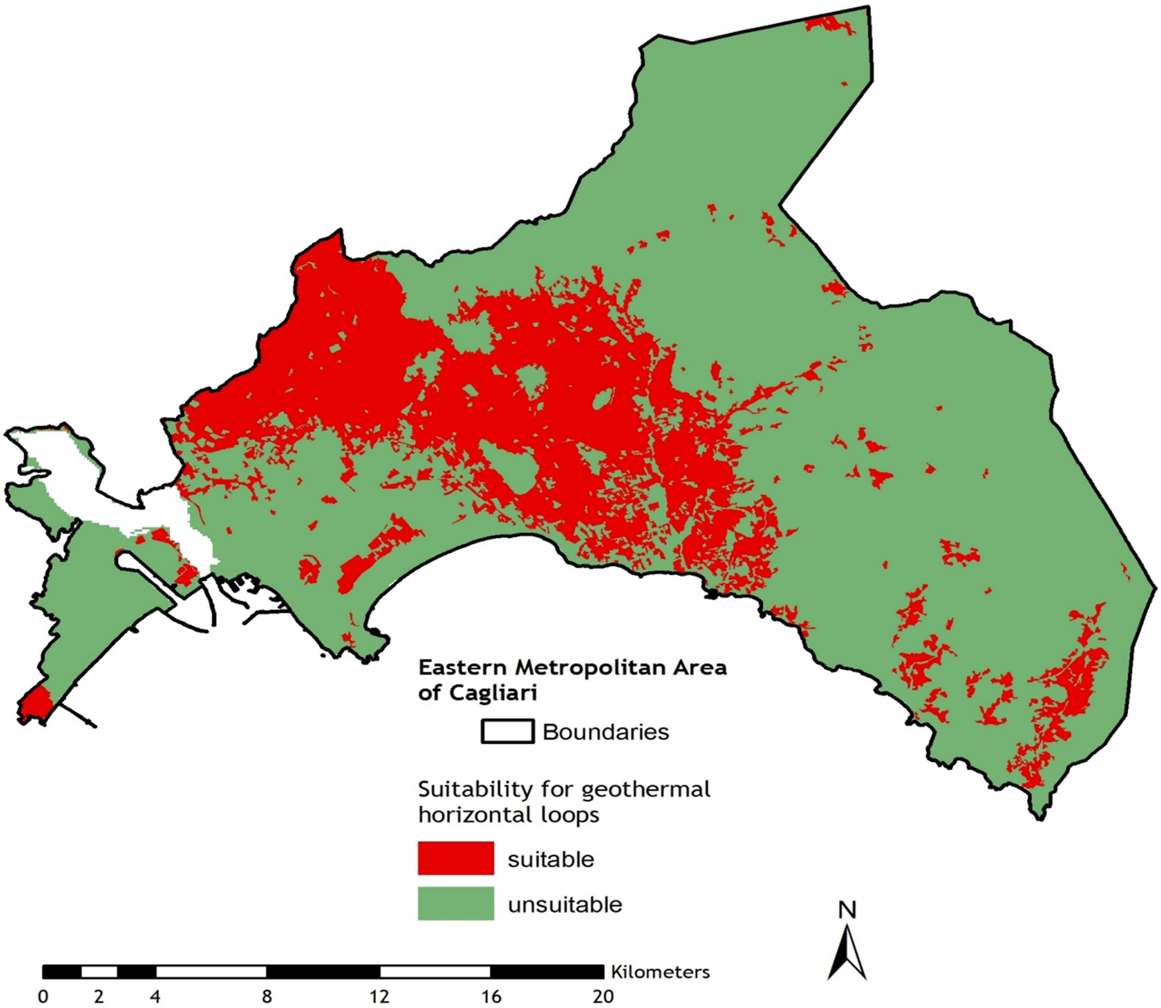


Figure 22: Geothermal potential estimation for horizontal loops, scale 1: 250.000.

5.6 Wood biomass energy potential estimation in the eastern metropolitan area of Cagliari

In this work, unsuitable areas were excluded and left for future consideration. As an added criterion, the practice of forestry was assumed. Landscape protection areas were not excluded from exploitation for correct forestry, which is permitted in these areas. Natura 2000 sites were overlaid with the forest areas (see Figure 23). Special Protected areas did not fall within the case study area and few Special areas of conservation were part of forests. According to Italian decrees, D.M. 2007 and 2009, regarding the minimum criteria for Natura 2000 sites, there were not prescriptions about the forest use; therefore, these areas were included in the evaluation of energy potential. The case study area covers approx. 59.000 ha. Forests occupy approx. 15.000 ha of the whole area.

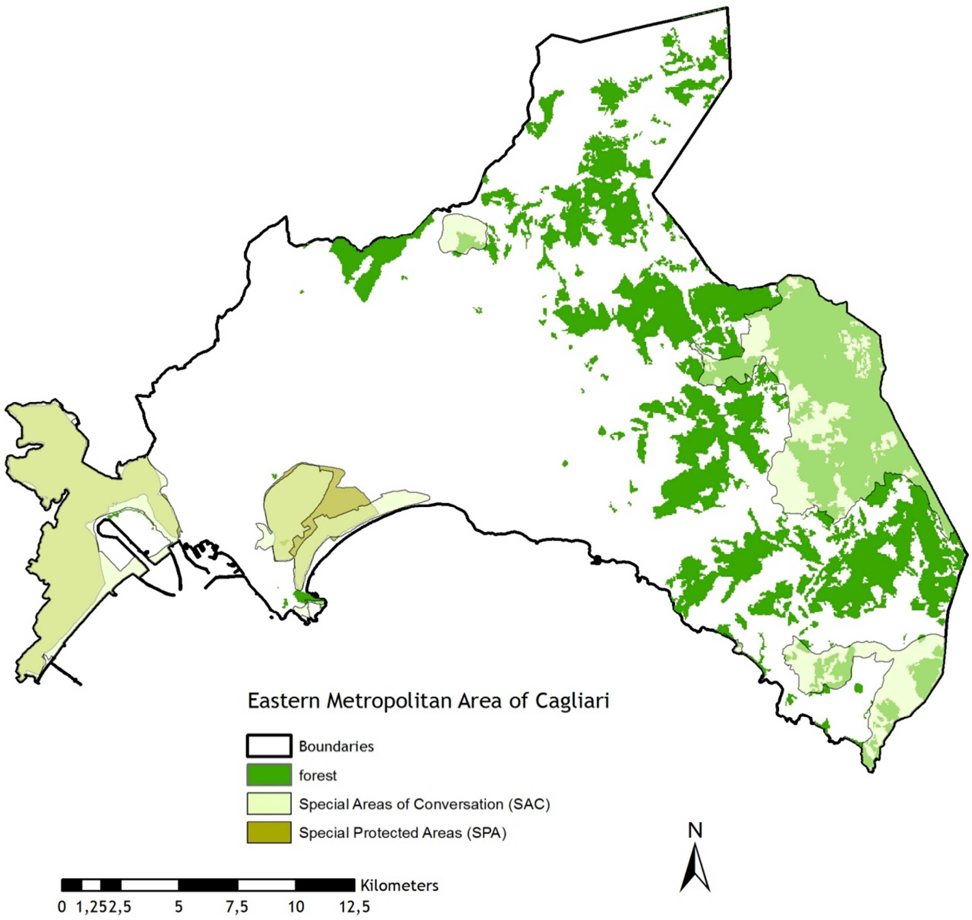


Figure 23: Forests and Natura 2000 sites, scale 1: 250.000.

Using Monte Carlo Integration, the equation for biomass energy potential was numerically integrated in accordance with two criteria: the appearance of afforested areas (V_i), within the radius of 15 kilometre distance between the potential location of settlement, and afforested areas (d_{ij}). The simulation was conducted for a section larger than the case study area to avoid errors at the calculation alongside the region boundary. The objective was to determine an integral which equates the above sum (cf. KOLONKO 2008). The smallest distance between a potential settlement and an afforested area, the larger the area under the graph and so the biomass-potential on this site. The simulation was conducted with Python (see text code Appendix 2). A grid with a width of 250 m was overlaid over the existing data. Subsequently, the area was sampled to determine if afforested areas existed within the defined perimeter. The 250 m grid was chosen because of the computation time required to perform the process. Nevertheless, a Monte Carlo Integration with more than 5.000 points is sufficient to guarantee a good output results. The averaged number of points in the areas was approximately 1 point in 250 [m^2]. The application of Monte Carlo Integration to existing data resulted in a biomass potential map (Figure 24).

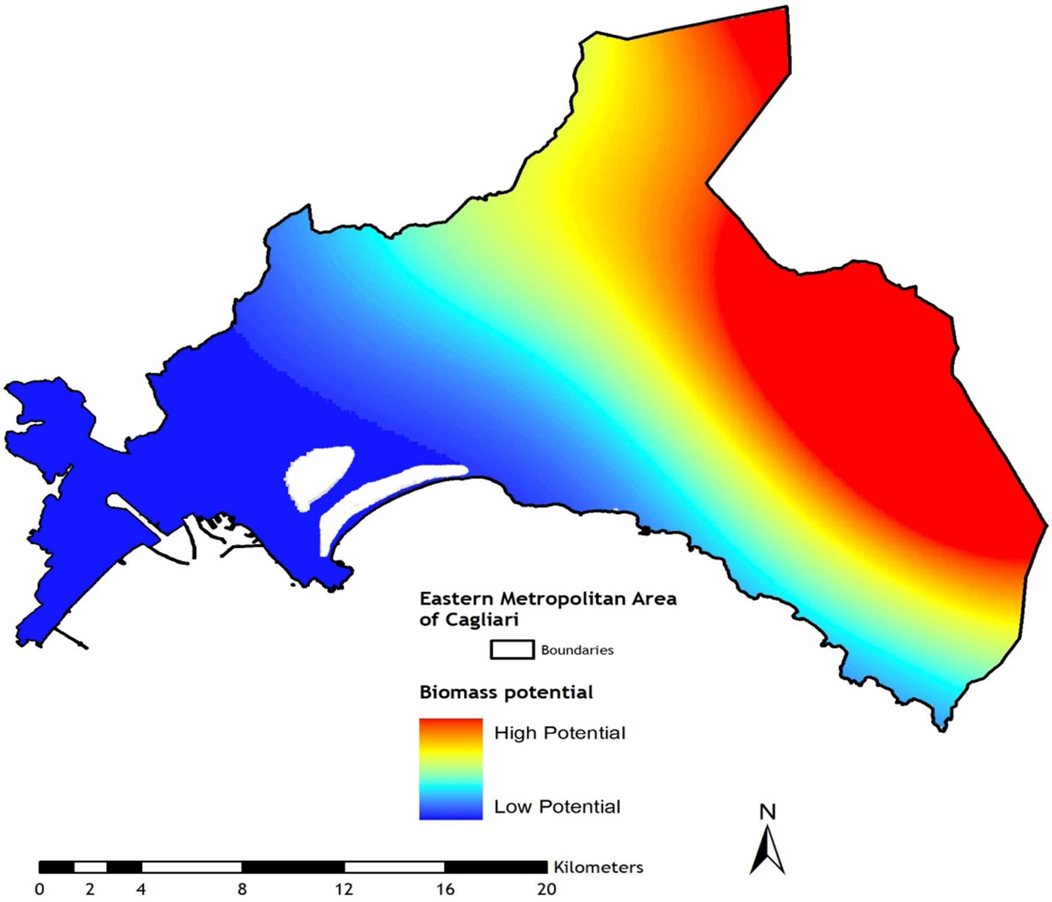


Figure 24: Biomass potential estimation, scale 1: 250.000

When compared to other maps resulting from this study, the resulting biomass potential estimation map i highly qualitative, given the omission of forestry considerations. These considerations would have included information regarding cubic meters of wood per square meter, or transportation systems and routes, for example. These data could only be considered in more details, if they were available.

5.7 A multi-criteria framework for energy efficient residential development

To prioritize the importance of each criterion according to expert preferences, weights were derived from pairwise comparison matrices, and the consistency of each matrix was tested. An example of this calculation can be found in Appendix 3: “Example of weights calculation and consistency test calculation (CR<0.1)”.

Table 16 the weights for each criterion assigned by experts.

Experts	WEIGHTS				
	Proximity to existing urban areas	Proximity to major roads and train lines	Distance from environmentally valuable and vulnerable areas or from protected areas	Proximity to water (lakes and rivers)	Slope gradient
German S. & AP.	0.20	0.22	0.31	0.14	0.13
German RP. & PA.	0.26	0.22	0.24	0.14	0.15
Italian S. & AP.	0.26	0.16	0.34	0.15	0.10
Italian RP. & PA.	0.25	0.20	0.23	0.17	0.15
English S. & AP.	0.29	0.26	0.21	0.11	0.12
English RP. & PA.	0.35	0.22	0.19	0.12	0.13
Claudia	0.25	0.13	0.54	0.03	0.05

Table 16: Weights for each criterion for new housing development as assigned by students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.) by each nationality.

The weights total 1. A higher weight corresponds to more consideration for the respective criteria. Furthermore, mean **μ** and standard deviation **σ** of the results were calculated. Broadly speaking, standard deviation is a widely used measure of the variability or dispersion of a distribution of scores (GHAHRAMANI & SAEED 2000: 438).

$$\sigma=\sqrt{\frac{\sum_{i}(x_i-\mu)^2}{N}} \quad (15)$$

i= 1,2..,N

x_i= raw score

μ= arithmetic average (mean)

N= number of scores

The standard deviation shows how much variation (spread) there is from the "average" (mean). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values (ibid.). If the mean and standard deviation of a normal distribution are known, it is possible to compute the percentile rank associated with any given score. In a normal distribution, about 68% of the scores are within one standard deviation of the mean and about 95% of the scores are within two standard deviations of the mean (ibid.). Figure 25 below is a normal distribution. It shows the percentage of cases between different scores as expressed in standard deviation units. For example, about 34% of the scores fall between the mean and one standard deviation above the mean.

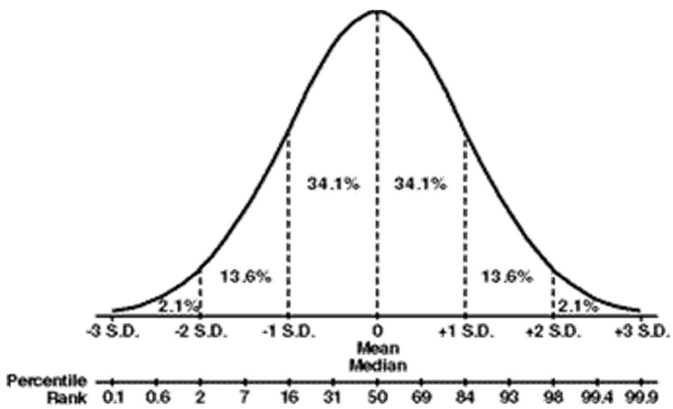


Figure 25: A Normal Distribution (GHAHRAMANI & SAEED 2000: 438).

In a normal distribution:

($\mu \pm \boldsymbol{\sigma}$) contains about 70% of the observations
($\mu \pm 2\boldsymbol{\sigma}$) contains about 95% of the observations
($\mu \pm 3\boldsymbol{\sigma}$) contains more than 99% of the observations

Table 17, 18, 19 show the values of the average and standard deviation for each criteria according to experts preferences.

FACTORS	German S. & AP.			German RP. & PA.		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Proximity to existing urban areas	0.20	0.10	48.25	0.26	0.13	48.98
Proximity to major roads and train lines	0.22	0.12	57.04	0.22	0.05	24.79
Distance from environmentally valuable areas	0.31	0.14	44.80	0.24	0.17	73.79
Proximity to water	0.14	0.12	86.46	0.14	0.06	43.07
Slope gradient	0.13	0.12	92.15	0.15	0.07	49.47

FACTORS	Italian S. & AP.			Italian RP. & PA.		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Proximity to existing urban areas	0.26	0.17	64.72	0.25	0.15	60.66
Proximity to major roads and train lines	0.16	0.11	67.63	0.20	0.11	55.41
Distance from environmentally valuable areas	0.34	0.17	50.06	0.23	0.18	76.22
Proximity to water	0.15	0.10	67.49	0.17	0.12	73.41
Slope gradient	0.10	0.15	148.24	0.15	0.10	68.44

FACTORS	English S. & AP.			English RP. & PA.		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Proximity to existing urban areas	0.29	0.10	34.36	0.35	0.10	29.00
Proximity to major roads and train lines	0.26	0.11	43.82	0.22	0.08	38.10
Distance from environmentally valuable areas	0.21	0.15	68.79	0.19	0.09	47.20
Proximity to water	0.11	0.06	53.40	0.12	0.06	47.29
Slope gradient	0.12	0.06	48.54	0.13	0.05	40.90

Table 17, Table 18, Table 19: Average and Standard Deviation (SD) of the weights for housing development of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).

The second suitability map (Figures 26) shows the housing development' preferences according to the weights calculated for each criteria.

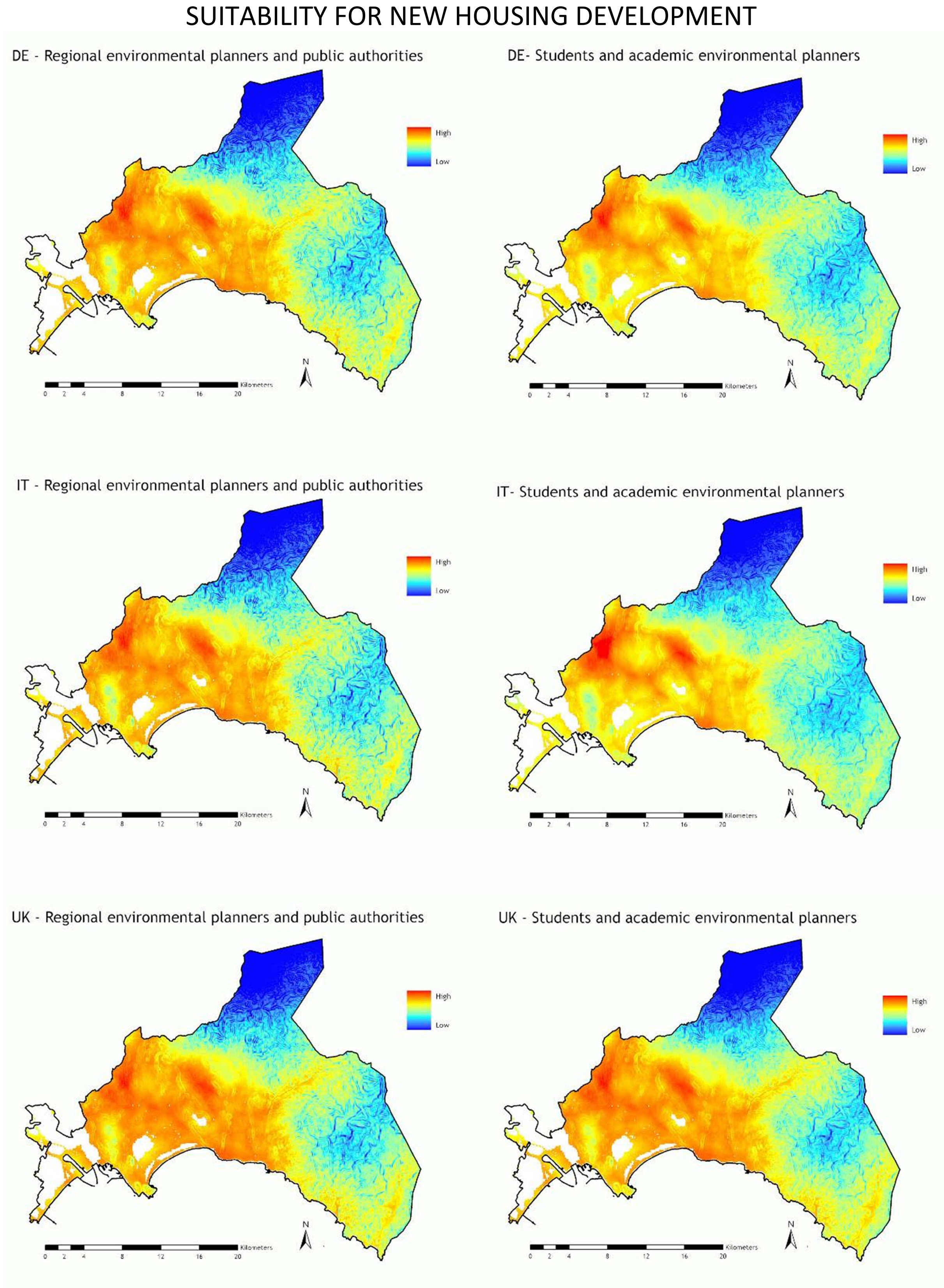


Figure 26: Suitability for new housing development from expert's perspectives.

Looking at Figure 26 it seems to be not a great variability between preferences of experts from each country. The red areas that were selected as best locations for new settlements are far from the valuable and vulnerable environmental areas (e.g. the Molentargius wetland, the S. Gilla lagoon and the Park of the "Sette Fratelli"). The English experts preferred a compact development close to the built-up areas

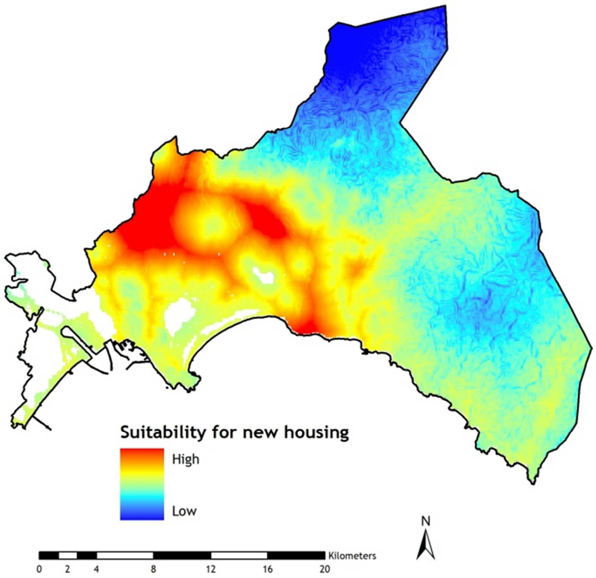


Figure 27 Suitability for new housing-author preference.

(S. & AP.: weight 0.29; RP. & PA.: weight 0,35). The German experts gave the same weight for a urban development near roads and train lines (0.22). About the distance from environmentally valuable and vulnerable areas, Italian and German students and academic planners expressed a similar preference (0.34; 0.31), as well as the Italian and German regional planners and public authorities (0.23; 0.24). The Italian experts preferred a development that is closed to lakes and rivers for the attractiveness (0.15; 0.17). German and Italian regional planners and public authorities gave the same consideration for the slope gradient (0.15). The suitability map by the author showed a compact development (0.25), taking into account the distance from the protected areas (0.54) (see Figure 27).

This preference was according to the prescriptions of the Landscape Plan of Sardinia with regard to the preservation of sensitive areas. In this case the new development was located near built-up areas as well as far from landscape protected areas or environmentally valuable areas. On the other hand, we had a high standard deviation which indicates that the data spread out over a large range of values between different expert groups. The SD as a % of the mean the values did not exceed 100% so the variations were not too great. The only case was about the consideration of the slope gradient by Italian academic planners which is 148.24%. The calculation of the average of the standard deviation in % of the mean showed different variability of the evaluation expressed in different countries (Table 20). For instance, there was more variation in the Italian results than the English ones.

Expert group	**DE-S.&AP.**	**DE-RP.&PA.**	**IT-S.&AP.**	**IT-RP.&PA.**	**UK-S.&AP.**	**UK-P.&PA**
Average of the SD in % of the mean	65.74	48.02	79.62	66.83	49.78	40.50

Table 20: Average of the Standard Deviation (SD) % of the mean for the housing development of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).

The third suitability maps (Figure 28-32) showed the experts preferences with micro power plants according to the weights calculated for each criteria (see Tables 21-25).

Criteria for new housing development with micro solar power plants	WEIGHTS					
	DE- S.&AP.	**DE- P.&PA**	**IT- S.&AP.**	**IT- P.&PA**	**UK- S.&AP.**	**UK- P.&PA**
Distance from landscape protected areas and other beauty areas	0.46	0.40	0.58	0.54	0.54	0.54
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	0.54	0.60	0.43	0.46	0.46	0.46

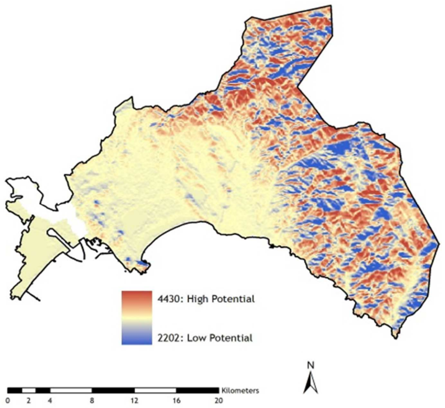
Criteria for new housing development with micro wind power plants	WEIGHTS					
	DE- S.&AP.	**DE- P.&PA**	**IT- S.&AP.**	**IT- P.&PA**	**UK- S.&AP.**	**UK- P.&PA**
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	0.26	0.31	0.35	0.40	0.30	0.35
Distance from Special Protection Areas (Natura 2000 sites) and others avifaunistic important areas	0.50	0.44	0.45	0.30	0.39	0.38
Distance from landscape protected areas and other beauty areas	0.25	0.25	0.19	0.30	0.31	0.28

Criteria for new housing development with geothermal vertical loops	WEIGHTS					
	DE- S.&AP.	**DE- P.&PA**	**IT- S.&AP.**	**IT- P.&PA**	**UK- S.&AP.**	**UK- P.&PA**
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	0.30	0.35	0.38	0.47	0.34	0.39
Distance from drinking water or aquifers	0.70	0.65	0.62	0.53	0.66	0.61

Criteria for new housing development with geothermal horizontal	WEIGHTS					
	DE- S.&AP.	**DE- P.&PA**	**IT- S.&AP.**	**IT- P.&PA**	**UK- S.&AP.**	**UK- P.&PA**
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	0.31	0.37	0.45	0.29	0.36	0.68
Distance from flooding areas	0.69	0.63	0.55	0.71	0.64	0.32

Criteria for new housing development with micro biomass power plants	WEIGHTS					
	DE- S.&AP.	**DE- P.&PA**	**IT- S.&AP.**	**IT- P.&PA**	**UK- S.&AP.**	**UK- P.&PA**
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	0.43	0.62	0.48	0.54	0.39	0.53
Distance from landscape protected areas and other beauty areas	0.57	0.38	0.52	0.46	0.61	0.47

Table 21, Table 22, Table 23, Table 24, Table 25: Weights for housing development with micro generation of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).



Sun energy potential
in terms of solar irradiation [Wh/m^2/day]
and experts preferences
for micro solar power plants

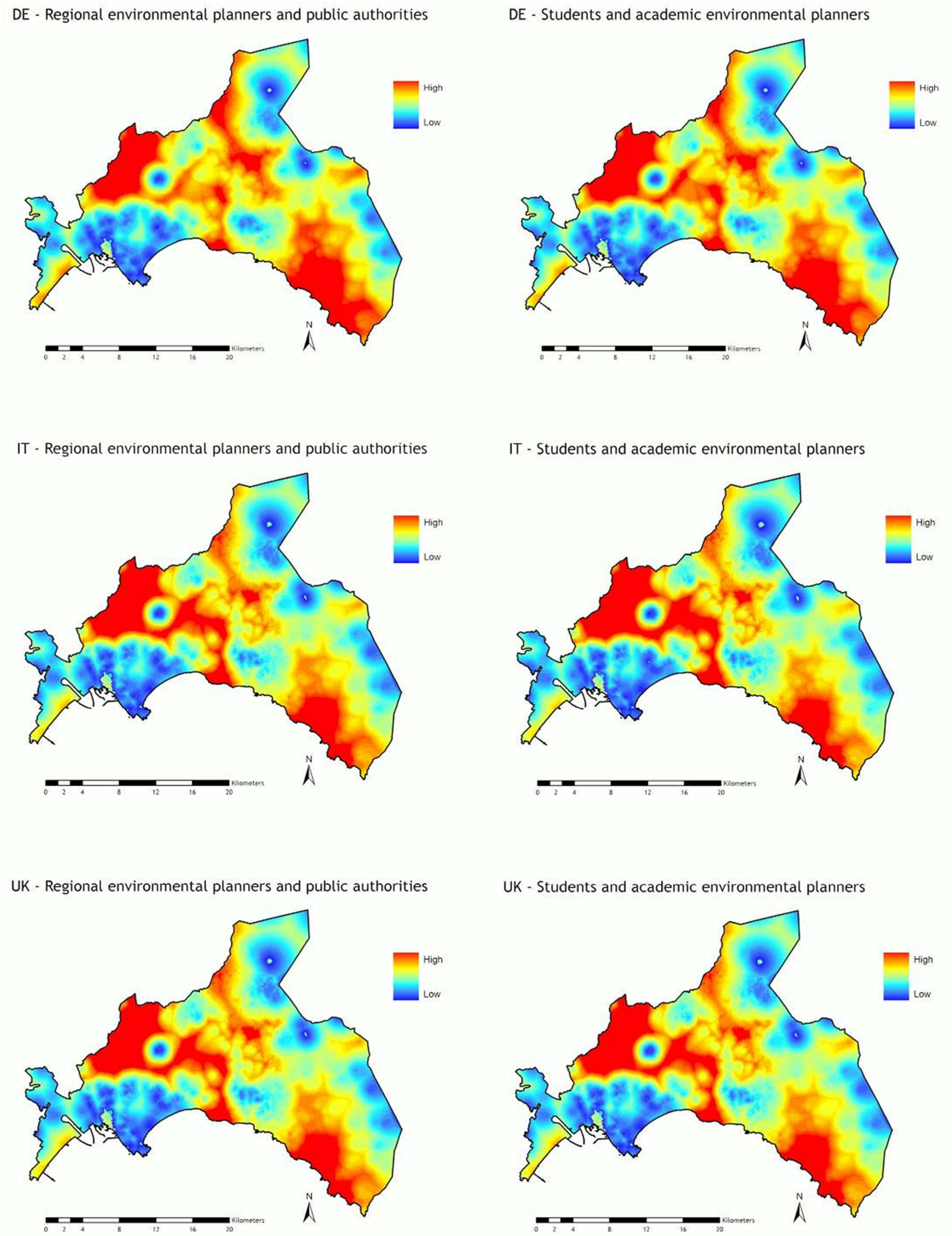


Figure 28 Solar energy potential and suitability for new housing development with micro solar power plants.

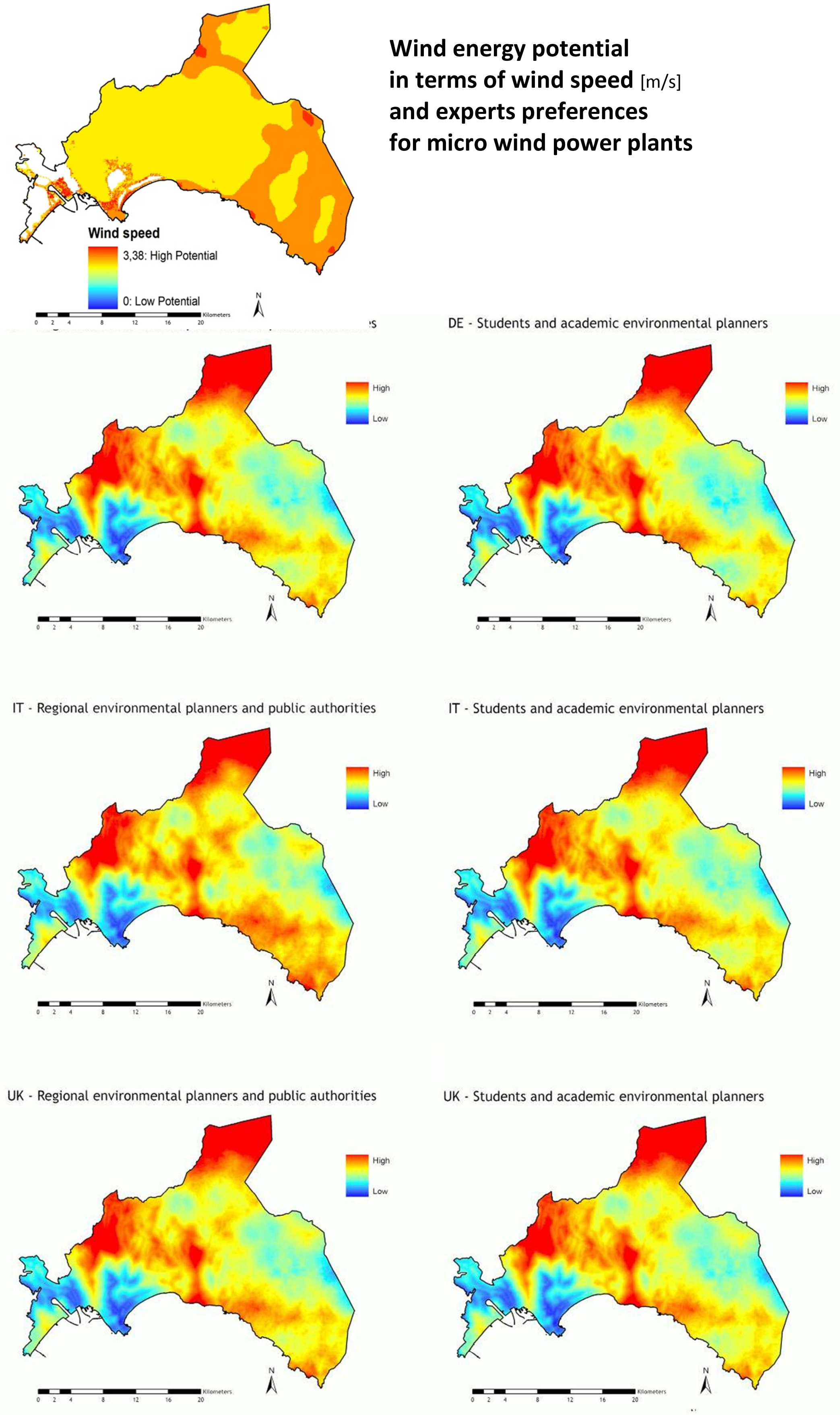


Figure 29 Wind energy potential and suitability for new housing development with micro wind power plants.

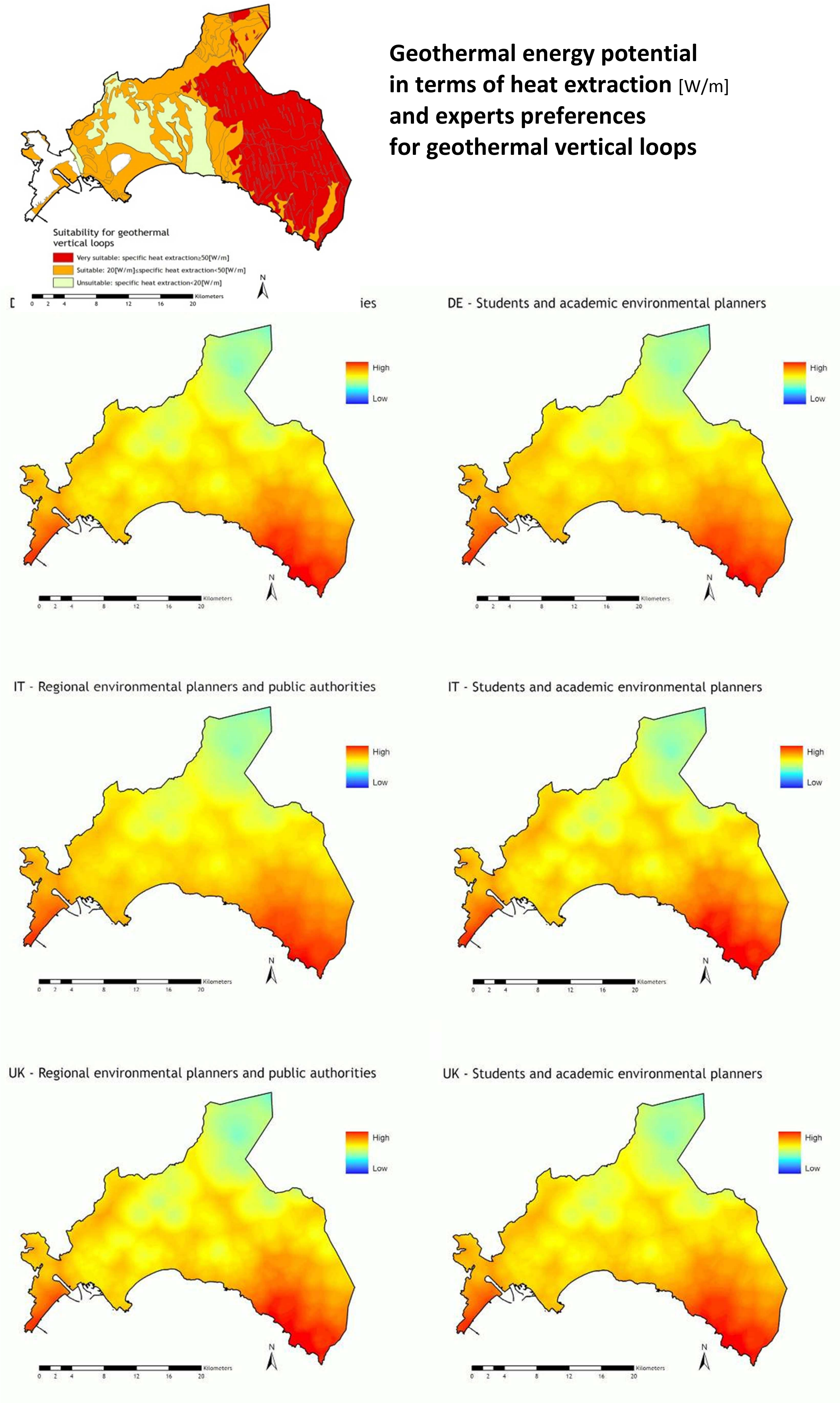
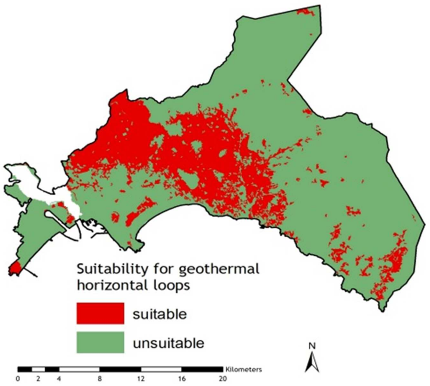


Figure 30 Geothermal energy potential and suitability for new housing development with geothermal vertical loops.



Geothermal energy potential and experts preferences for geothermal horizontal loops

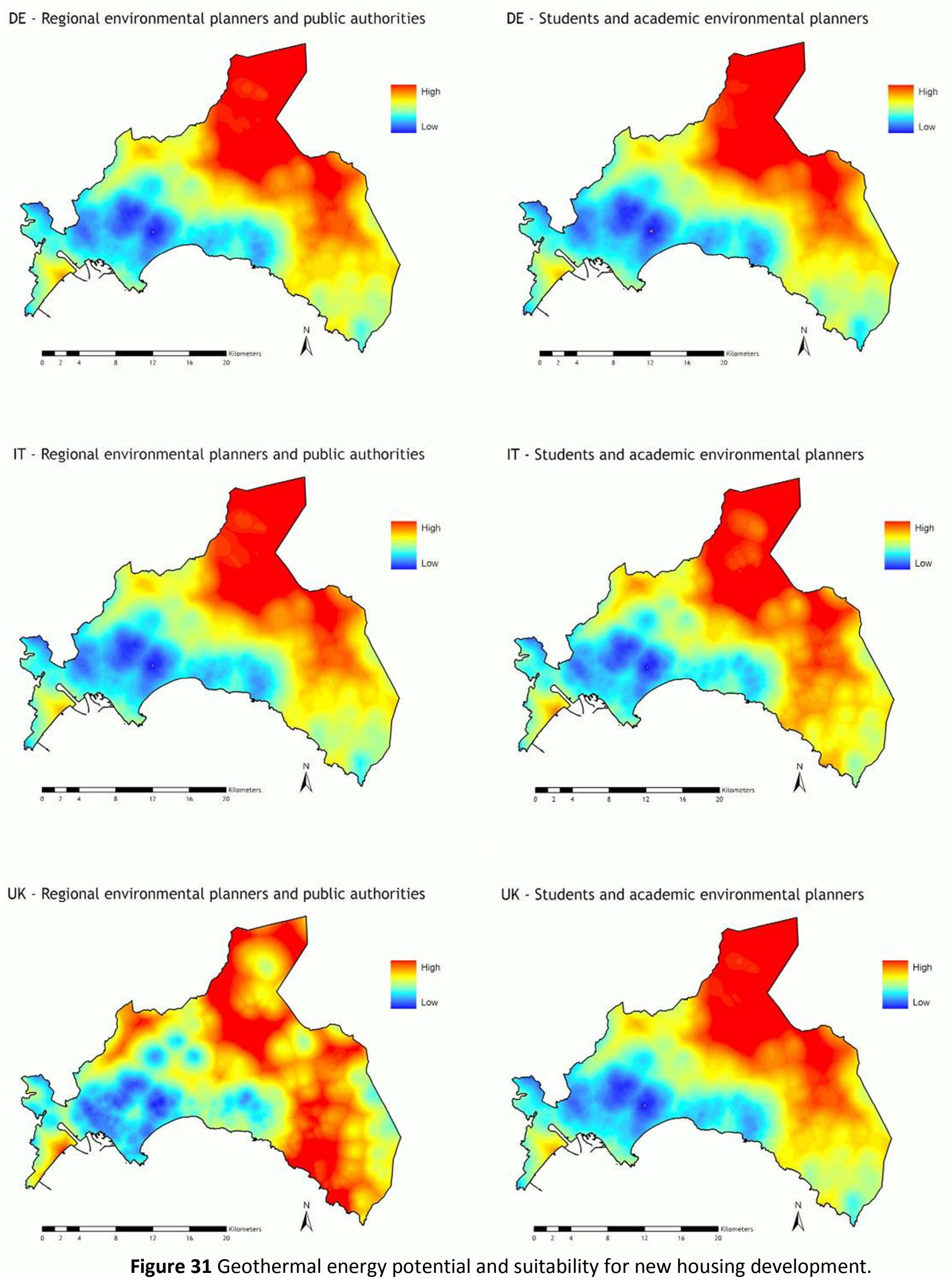
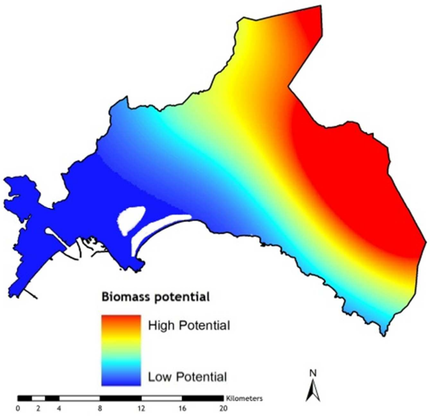


Figure 31 Geothermal energy potential and suitability for new housing development. with geothermal horizontal loops.



Biomass energy potential and experts preferences for micro biomass power plants

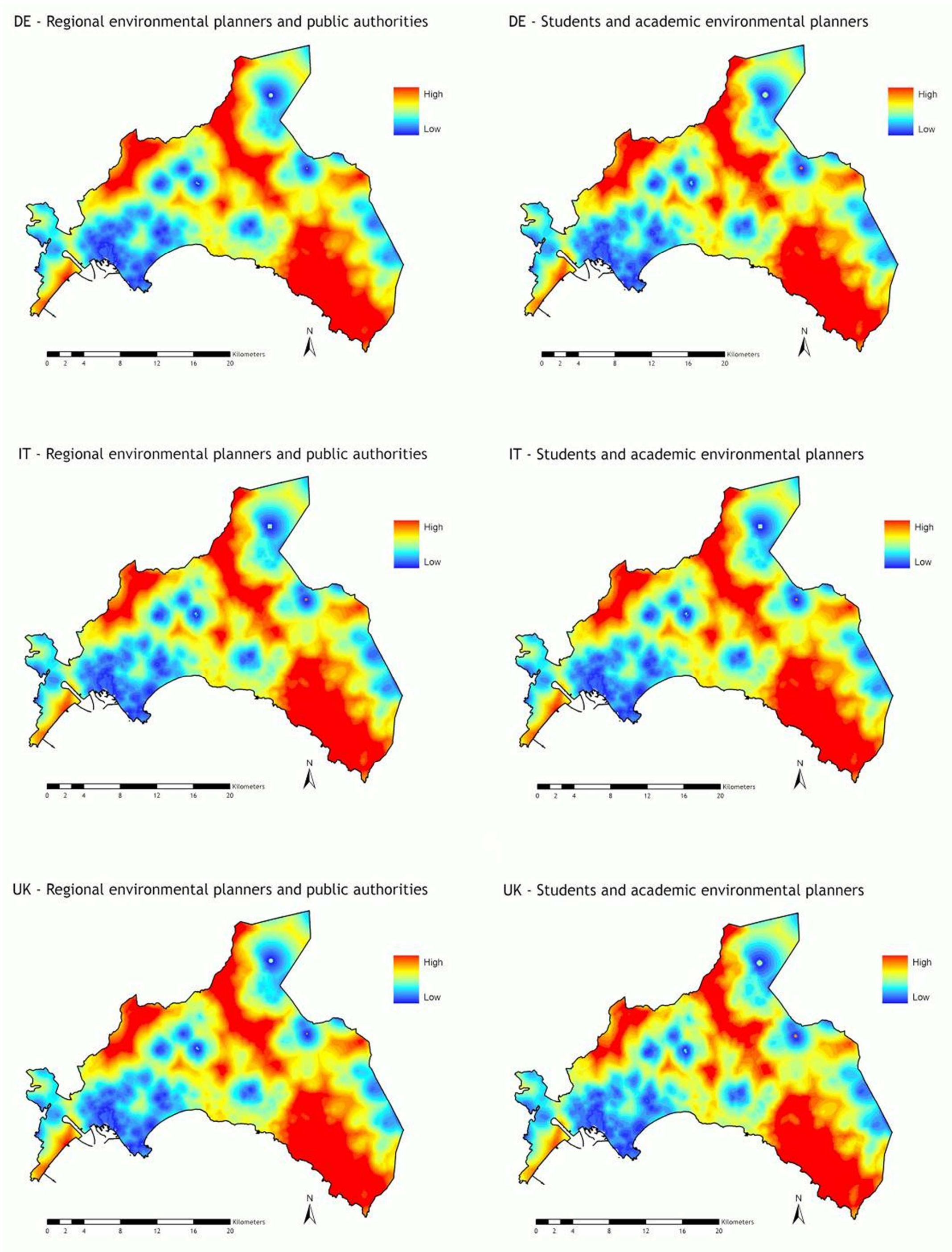


Figure 32 Biomass energy potential and suitability for housing development with micro biomass power plants.

The results of the survey showed similarities and differences between stakeholder group preferences from the three countries. This outcome stems from differences in the planning systems and on the confidence/acceptance for micro renewables. After the calculation of the weights for new settlements development and for new settlements with micro generators, both suitability maps were overlaid with the energy potential for each micro renewable technology and for each expert group.

The suitability maps, identified through the experts survey, were compared with the micro energy potentials. It is interesting to see that there were many areas where the energy potential was high and also according to the experts preferences new settlement with renewable energies should be localized. The solar irradiation is high (almost similar) for the whole case study area. Nevertheless, areas where the potential is relatively lower (areas in blue) (see Figure 28) because of the terrain aspect and slope, should be excluded.

The German students and academic planners (weight: 0.54) and regional planners and public authorities (weight: 0.60) gave more consideration to the visual impact caused by solar panels and solar thermal collectors on the cultural heritage. Italian academic (0.58) and environmental planners (0.54) and English academic (0.54) and environmental planners (0.54) by the contrast considered more intrusive the solar power plants near landscape protected areas and other beauty areas.

The author (Figure 33) like Italian and English experts gave an higher weight to the distance from the landscape areas (0.83) and a smaller one to historical/cultural heritage (0.17), because there are lots of studies and possibility to integrate the solar power plants e.g. in historical centre (EUROSOLAR, 2001; Office of the Deputy Prime Minister 2004; Cooke et al. 2007). On the other hand, new housing development with micro solar power plants near historical or landscape protected areas should be carefully examined case by case taking into account variability, diversity and characteristics of landscapes.

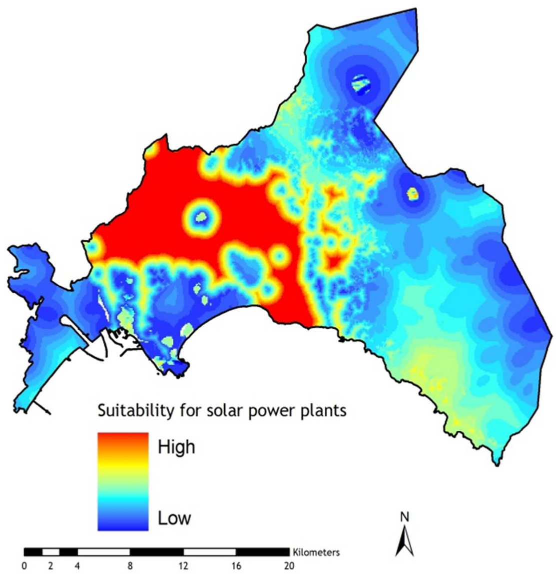


Figure 33 Suitability for micro solar power plant- author preference

The wind potential varies over the Cagliari region. From the wind potential map the most suitable areas (which are in red and orange) for wind use can be extrapolated and overlaid with the expert preferences. In that case it would be also possible in addition to select a number of alternatives and then take into account micro wind turbine models and costs to include also technical and economical consideration for the plan of new residential areas with micro wind turbines.

German experts paid more attention to the environmental impact represented by the distance from avifaunistic important areas (respectively weights S. & AP.: 0.50 and RP. & PA. : 0.44). On the contrary Italian experts expressed their preferences to the visual impact near historical and cultural facilities (S. & AP.: 0.35; RP. & PA.0.40) while English experts assigned almost equal weights to all three criteria including the visual impact to landscape evaluable areas.

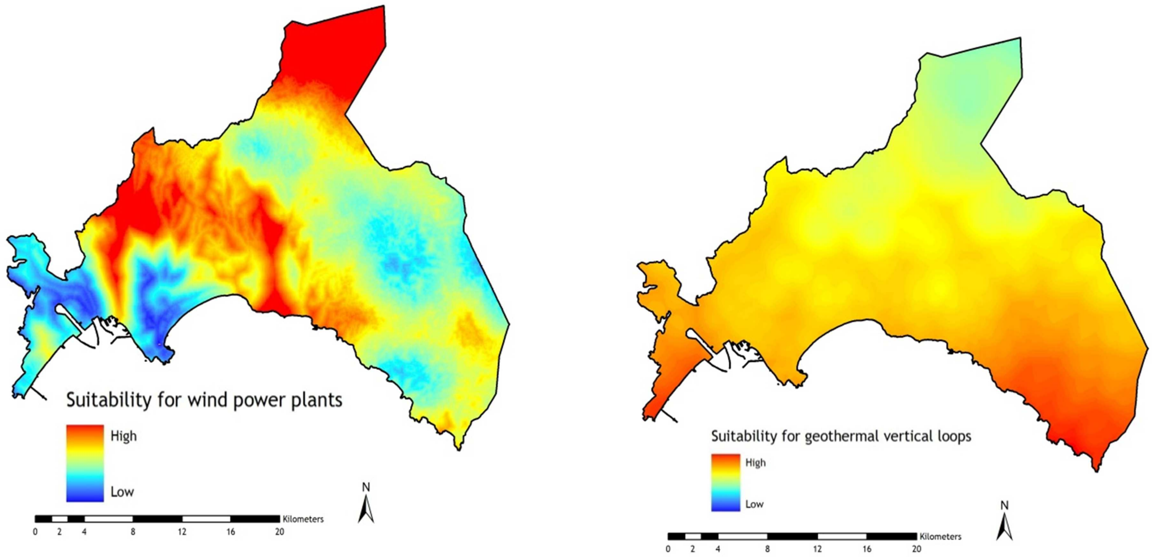


Figure 34, 35: Suitability for micro wind power plants author preference; Suitability for GHL – author preference

Like the German experts the author gave an highest weight to the environmental impact (collisions) caused by wind turbines on birds and bats (0.71) to preserve the biodiversity and sensible or vulnerable ecosystems (Figure 34).

The geothermal potential map for vertical loops and the different maps obtained from expert preferences present analogies. The areas in red and orange located on the East of the Cagliari metropolitan areas have an high energy potential and were also the most favorite sites chosen by all stakeholder groups.

All experts, in particular the Italian regional planners and public authorities (0.71) and the German students and academic planners (0.70), assigned the highest weight to the criteria "Distance from drinking water or aquifers". The author paid also more attention to that criteria (0.75) (see Figure 35), because the vertical loops should be buried up to 100 m and in some cases can modify the groundwater flow with consequences on the new settlements (cf. SASS ET AL. 2009) and on the water quality and temperature. For instance, in Germany that was a country with a mature experience in this field, it is obligatory to have a specified authorization to bore in drinking water protected areas ("Wasserschutzgebiete") (cf. TECHNISCHE REGEL DVGW-ARBEITSBLATT W 115 2006).

The geothermal energy potential map for geothermal horizontal loops and the suitability map of the experts groups showed no compliance. In that case it would be important to make decisions according to others criteria or needs that can be considered in addition to those selected for this work. Like for the geothermal vertical loops preferences, the experts were concordant in identifying more important criteria "Distance from flooding areas" (average 0.63). The only one stakeholder group with contrary opinion was represented by the English regional planners and public authorities that paid more attention to the cultural and historical heritage (0.32). The author assigned the same preference for both criteria by assigning the same weight (0.5), because an inappropriate decision about the location can completely defeat the efficiency of the geothermal horizontal loops or damage the cultural heritage (Figure 36). So the priority would be to exclude contemporaneously those areas.

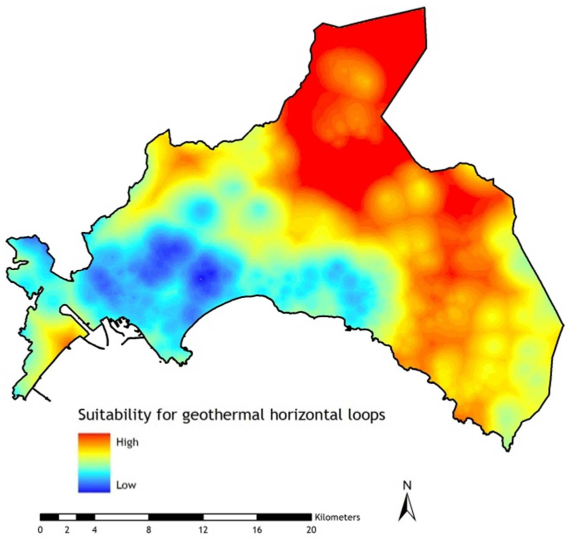


Figure 36 Suitability for GHL – author preference .

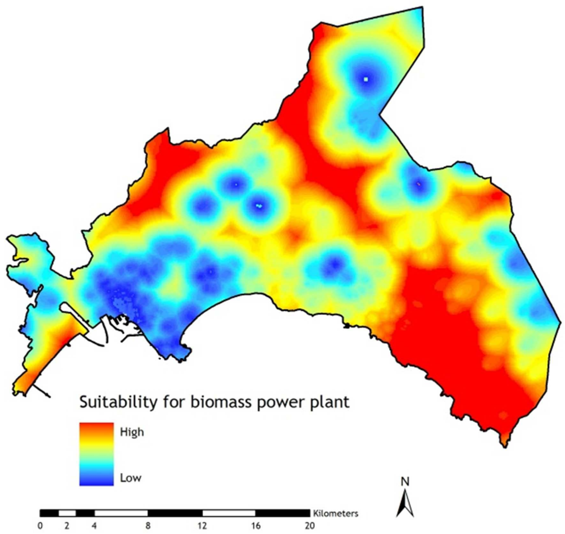


Figure 37: Suitability for biomass – author preference.

Only few areas located in the East of the metropolitan area showed a good biomass potential and were at the same time suitable according to the expert preferences. In this case it would be suggested to consider more important the energy potential, because of the presence of the biomass resource. In fact the use of biomass is from economic perspective not convenient in locations that are too far from forest areas.

Italian experts assigned similar weight about the visual impact of additional chimney for a single power plant or a central power plant near cultural/historical areas (0.48; 0.47) and landscape areas (0.52; 0.53). German regional planners and public authorities and English students and academic planners were of contrary opinion. The German regional planners and public authorities (0.62) paid more attention to the visual impact on the historical landscape, by the contrary the English academic planners (0.61) to the visual impact on landscape evaluable areas. The author agreed with the German environmental planners (0.83), because the flue can affect views or can break the profile of the houses in particular near historical sites (Figure 37). For the same reasons also a central power plant near those area could damage the landscape quality.

Table 26 shows the average spread of the data that is quantified by the average of the standard deviation.

Average of the SD in % of the mean						
Experts	Solar power plants	Wind power plants	Geother. vertical loops	Geother. horizontal loops	Biomass Power plants	Average
German students and academic planners	49.49	43.98	55.31	49.42	26.57	46.15
German regional planners and public authorities	44.34	51.49	48.21	48.86	51.49	48.90
Italian students and academic planners	57.39	58.46	74.56	67.57	58.17	63.23
Italian regional planners and public authorities	50.53	43.72	61.62	63.68	51.44	54.20
English students and academic planners	38.96	50.35	56.03	53.15	50.72	49.90
English regional planners and public authorities	41.37	38.67	67.62	68.19	52.24	53.70

Tab. 26: Average of the SD in % of the mean for all weights of micro generation

Table 26 shows that the standard deviation had more variability for some micro generation technologies than others. This might be due to differences in familiarity with the techniques or the extent to which they are considered appropriate in different countries. To the German students and academic planners was assigned the lowest value of the average of the standard deviation (26.57) about the preferences for biomass power plans. In fact the German academic planners were almost from the Leibniz University of Hannover, where many studies were conducted on biomass suitability and environmental impacts.

The English students and academic planners had almost the same opinion about the localization of new settlements with micro solar power plants (38.96). In general, solar energy was well accepted as the best option available today for energy production, because the technology is more mature compared to other renewables.

On the contrary, the Italian and English students and academic planners presented the largest variability of data about the geothermal vertical loops (74.56; 67.62). Geothermal energy was more common in Germany than in the others two countries. Due to this fact it may be also possible to give a reason why the preferences varied so much. In general the German experts have the smallest variability (46.15; 48.90), by the contrast Italian experts have the largest one (63.23; 54.20).

The calculation of the average and standard deviation for all the weights show that the standard deviation is always <100% of the average. So the spread of the weights were not too great.

The following tables present the results for each group of criteria of all micro renewable technologies according to the expert preferences (Tables 27-41).

FACTORS for micro solar power plants	German S.&AP.			German P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from landscape protected areas and beauty areas	0.46	0.25	53.53	0.40	0.21	53.21
Distance from historic/cultural facilities	0.54	0.25	45.45	0.60	0.21	35.48

FACTORS for micro wind power plants	German S.&AP.			German P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.26	0.14	56.23	0.31	0.15	47.88
Distance from avifaunistic important areas	0.50	0.20	40.59	0.44	0.16	36.92
Distance from landscape protected areas and beauty areas	0.25	0.09	35.11	0.25	0.07	25.17

FACTORS for geotherm. vertical loops	German S.&AP.			German P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.30	0.23	77.38	0.35	0.22	62.94
Distance from drinking water or aquifers	0.70	0.23	33.24	0.65	0.22	33.48

FACTORS for geotherm. horizontal loops	German S.&AP.			German P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.31	0.21	68.27	0.37	0.23	61.34
Distance from flooding areas	0.69	0.21	30.57	0.63	0.23	36.38

FACTORS for micro biomass power plants	German S.&AP.			German P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.43	0.13	30.53	0.62	0.24	39.10
Distance from landscape protected areas and beauty areas	0.57	0.13	22.61	0.38	0.24	63.78

Table 27, Table 28, Table 29, Table 30, Table 31: Average and Standard Deviation (SD) of the weights for micro generation (solar, wind, geothermal and biomass technologies) from German students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).

FACTORS for micro solar power plants	Italian S.&AP.			Italian P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from landscape protected areas and beauty areas	0.58	0.28	48.79	0.54	0.25	46.41
Distance from historic/cultural facilities	0.43	0.28	66.00	0.46	0.25	54.65

FACTORS for micro wind power plants	Italian S.&AP.			Italian P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.35	0.26	74.18	0.40	0.18	44.92
Distance from avifaunistic important areas	0.45	0.25	55.85	0.30	0.13	42.95
Distance from landscape protected areas and beauty areas	0.19	0.09	45.36	0.30	0.13	43.30

FACTORS for geotherm. vertical loops	Italian S.&AP.			Italian P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.38	0.35	92.81	0.47	0.26	86.67
Distance from drinking water or aquifers	0.62	0.35	56.31	0.53	0.26	36.16

FACTORS for geotherm. horizontal loops	Italian S.&AP.			Italian P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.45	0.33	74.74	0.29	0.26	82.47
Distance from flooding areas	0.55	0.33	60.40	0.71	0.26	44.89

FACTORS for micro biomass power plants	Italian S.&AP.			Italian P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.48	0.29	60.10	0.54	0.25	54.11
Distance from landscape protected areas and beauty areas	0.52	0.29	56.23	0.46	0.25	48.78

Table 32, Table 33, Table 34, Table 35, Table 36: Average and Standard Deviation (SD) of the weights for micro generation (solar, wind, geothermal and biomass technologies) from Italian students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).

FACTORS for micro solar power plants	English S.&AP.			English P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from landscape protected areas and beauty areas	0.54	0.19	35.71	0.54	0.21	38.39
Distance from historic/cultural facilities	0.46	0.19	43.20	0.46	0.21	44.36

FACTORS for micro wind power plants	English S.&AP.			English P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.30	0.19	65.03	0.35	0.14	41.06
Distance from avifaunistic important areas	0.39	0.20	50.69	0.38	0.14	36.38
Distance from landscape protected areas and beauty areas	0.31	0.11	35.34	0.28	0.11	38.56

FACTORS for geotherm. vertical loops	English S.&AP.			English P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.34	0.25	74.26	0.39	0.32	82.42
Distance from drinking water or aquifers	0.66	0.25	37.79	0.61	0.32	52.83

FACTORS for geotherm. horizontal loops	English S.&AP.			English P.&PA l		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.36	0.25	67.90	0.68	0.30	43.34
Distance from flooding areas	0.64	0.25	38.39	0.32	0.30	93.04

FACTORS for micro biomass power plants	English S.&AP.			English P.&PA		
	AVERAGE	SD	SD in terms % of the average	AVERAGE	SD	SD in terms % of the average
Distance from historic/cultural facilities	0.39	0.24	61.42	0.53	0.26	49.23
Distance from landscape protected areas and beauty areas	0.61	0.24	40.01	0.47	0.26	55.26

Table 37, Table 38, Table 39, Table 40, Table 41: Average and Standard Deviation (SD) of the weights for micro generation (solar, wind, geothermal and biomass technologies) from English students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).

After the creation of the suitability maps from expert perspective, the result maps were obtained by overlaying with the same weight the energy potential maps, the housing development map and the micro generation preferences map using the raster calculator of the Spatial Analyst in Arc GIS (Figures 38-42).

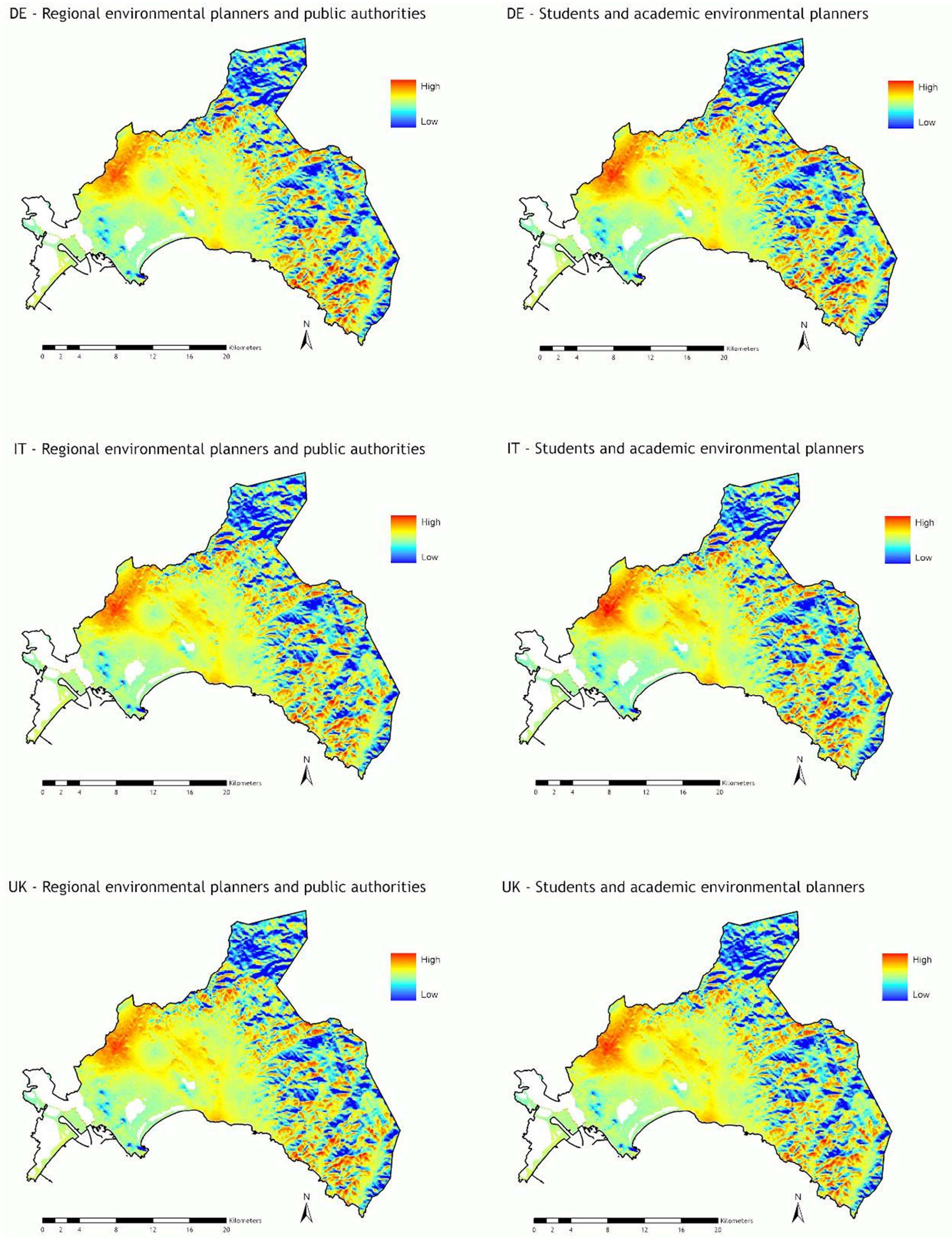


Figure 38: Suitability for housing development with micro solar power plants.
taking into account the solar energy potential.

Suitability for housing development with micro wind power plants taking into account the wind energy potential

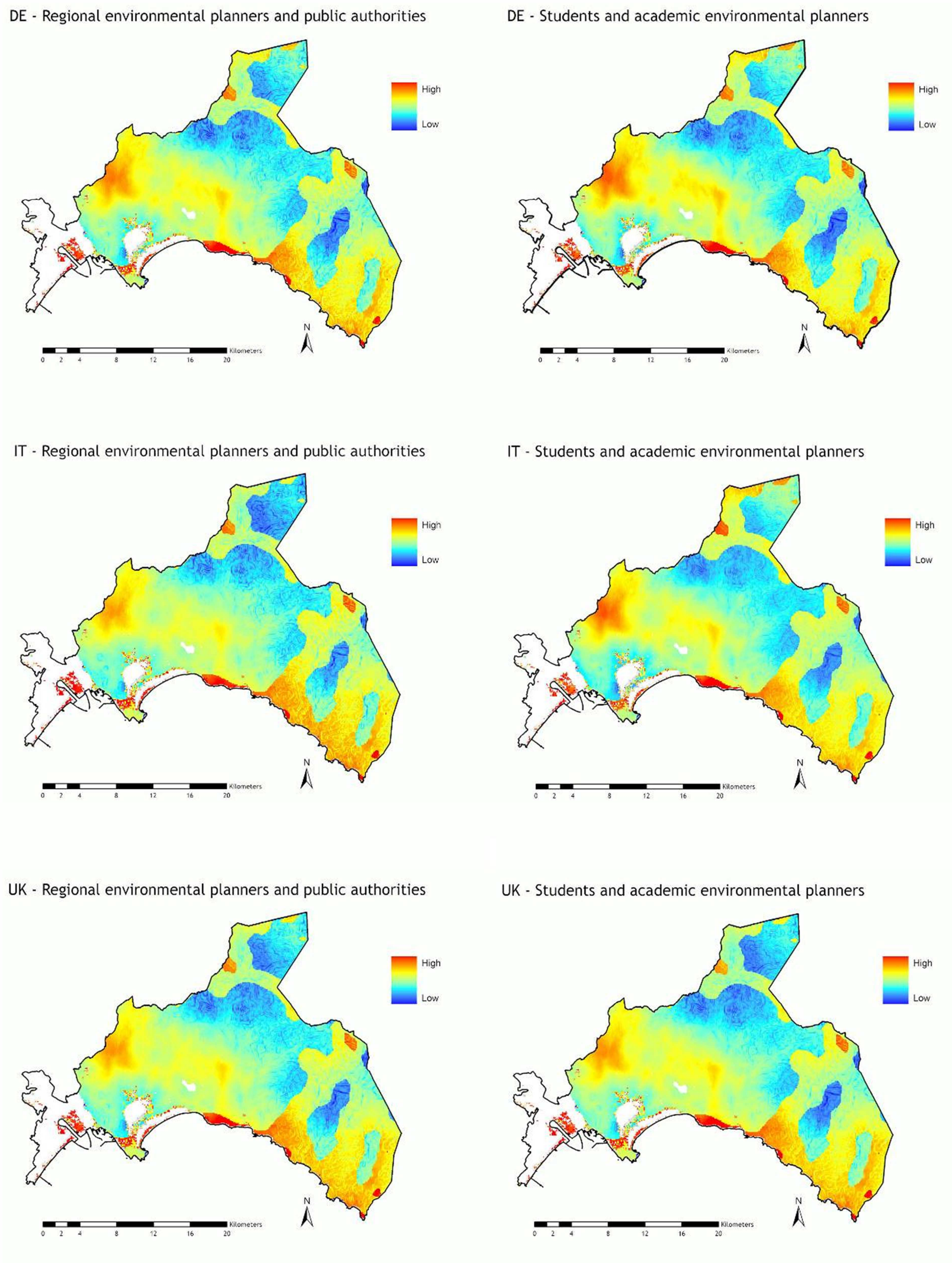


Figure 39: Suitability for housing development with micro wind power plants.
taking into account the wind energy potential.

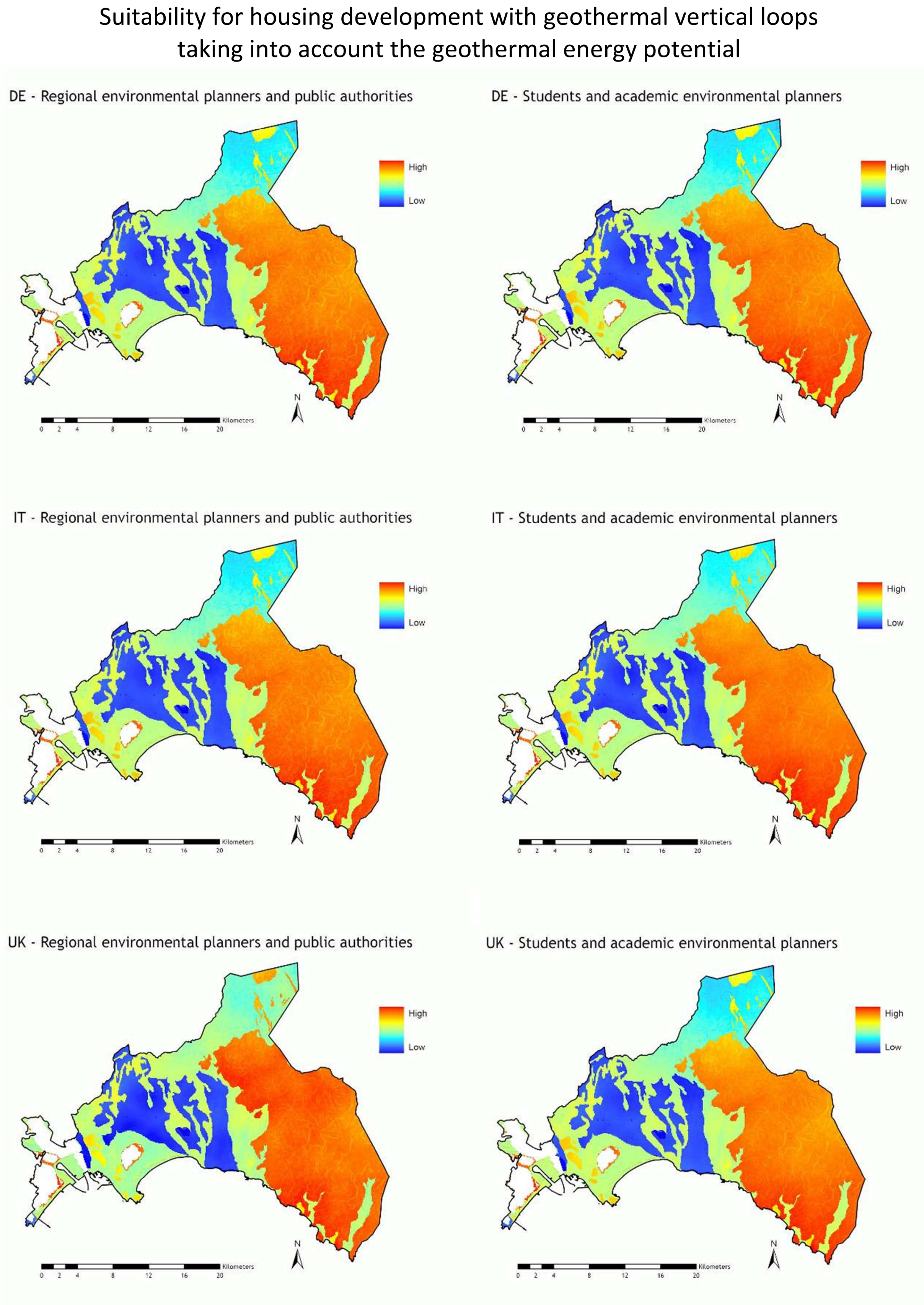


Figure 40: Suitability for housing development with geothermal vertical loops taking into account the geothermal energy potential.

Suitability for housing development with geothermal horizontal loops taking into account the geothermal energy potential

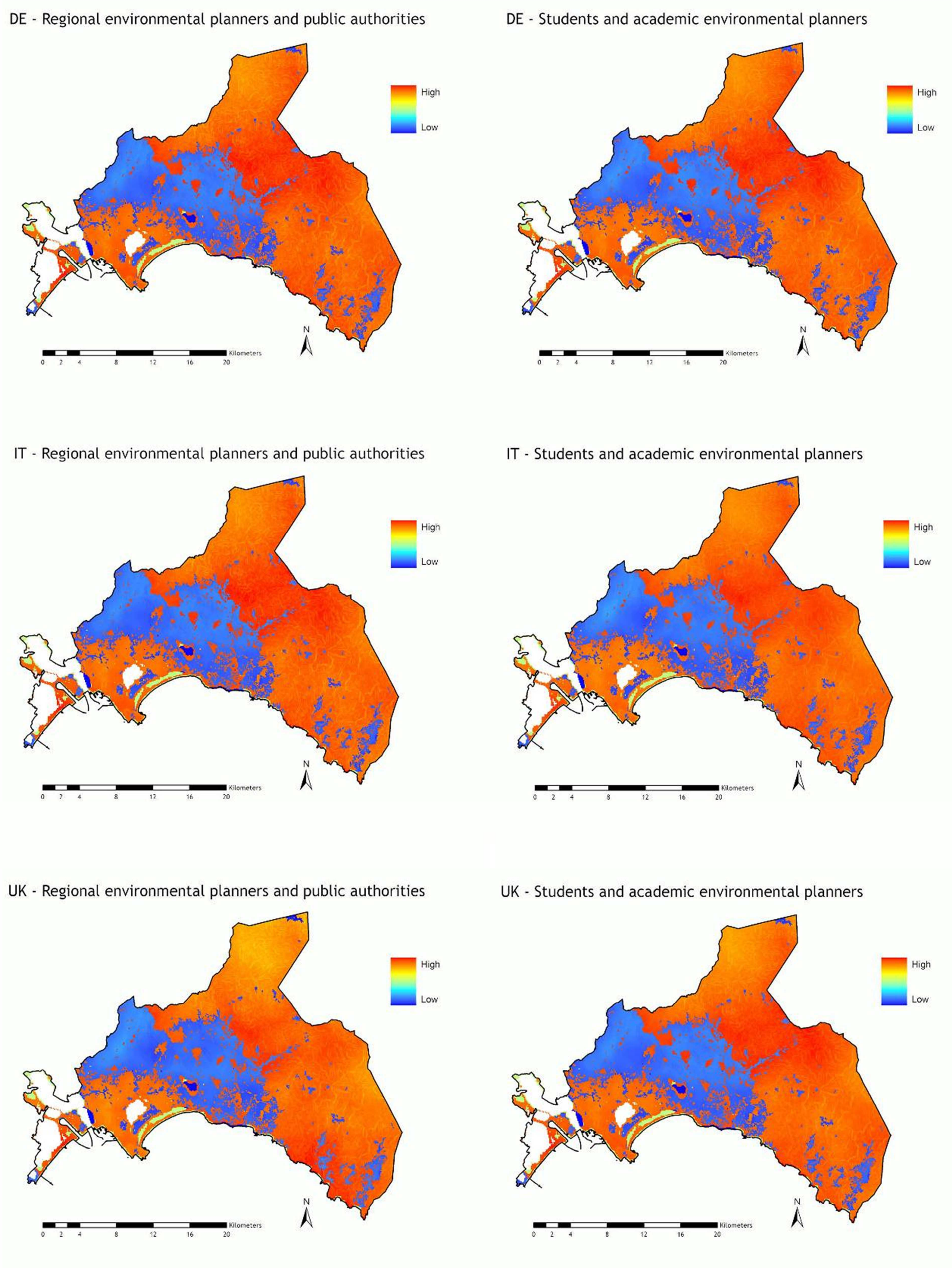


Figure 41: Suitability for housing development with geothermal horizontal loops. taking into account the geothermal energy potential.

Suitability for housing development with biomass power plants
taking into account the biomass energy potential

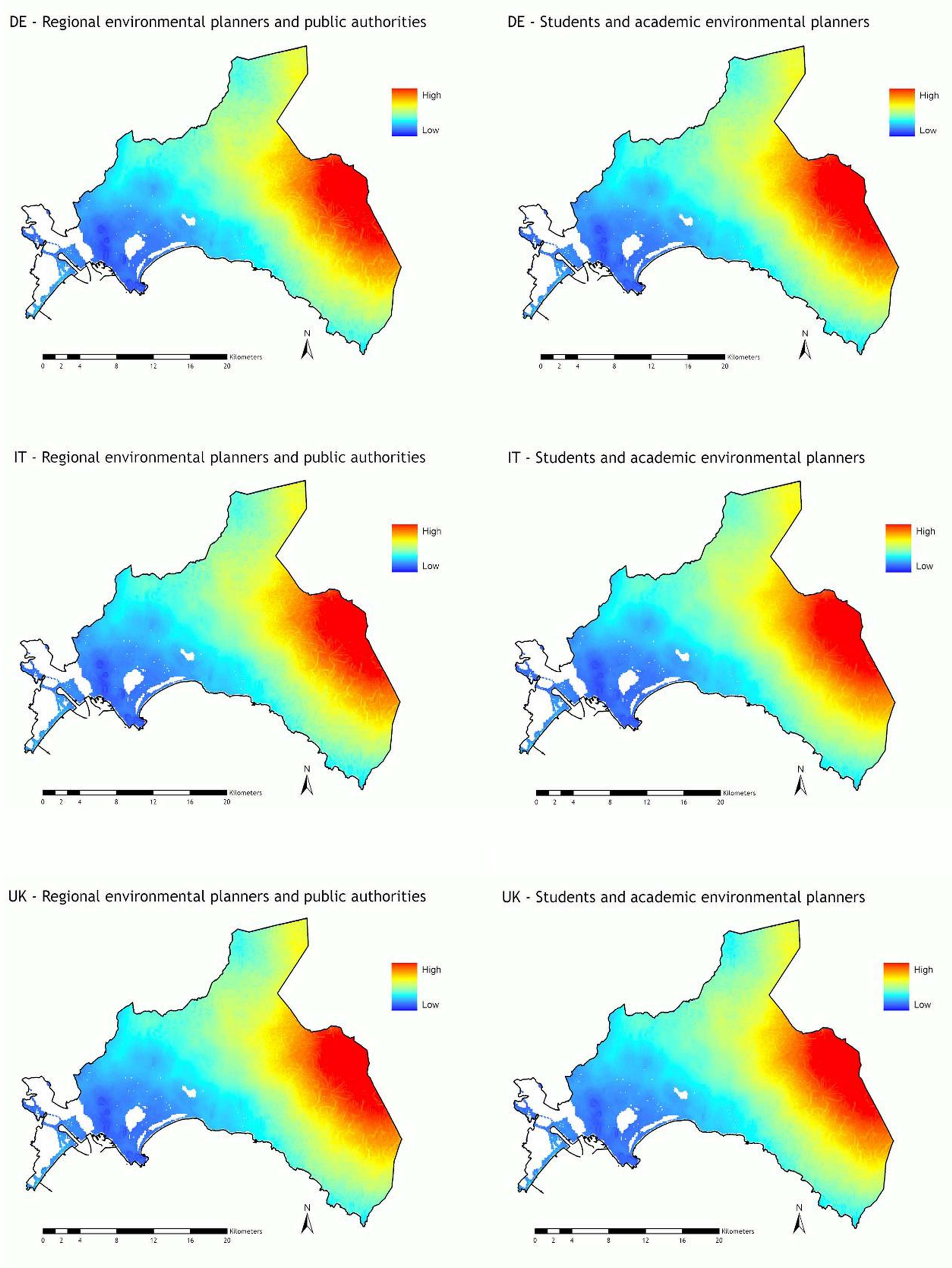


Figure 42: Suitability for housing development with biomass power plants
taking into account the biomass energy potential.

Finally, the resultant maps were multiplied by the relevant Boolean constraints to mask out restriction areas, which were: build-up areas, water surfaces and areas with high hydro geological instability. Final maps range from 0 to 255 for non-constrained locations (Figures 43-47).

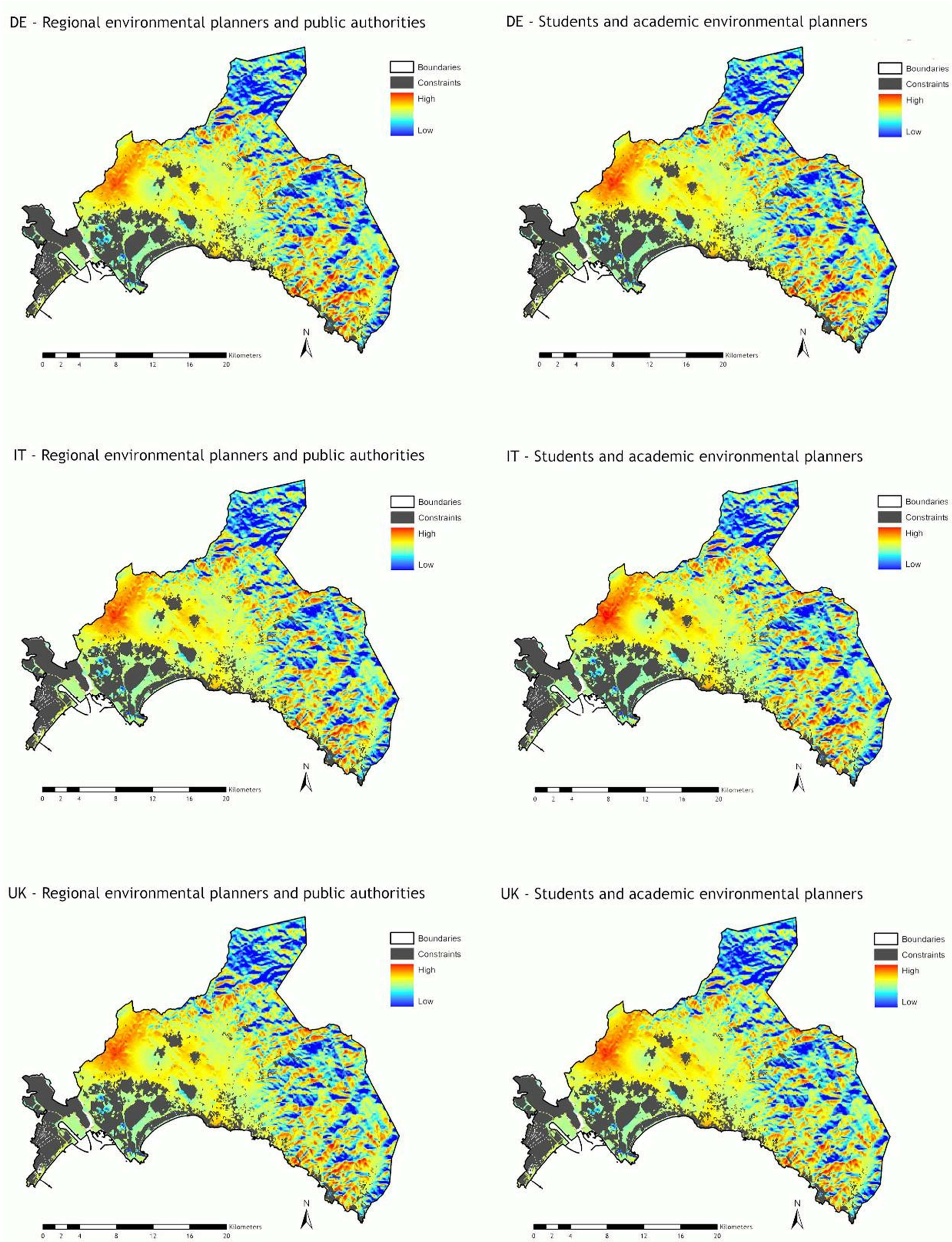


Figure 43: Suitability for housing development with micro solar power plants. taking into account the solar energy potential and the constraints.

Suitability for housing development with micro wind power plants
taking into account the wind energy potential and the constraints

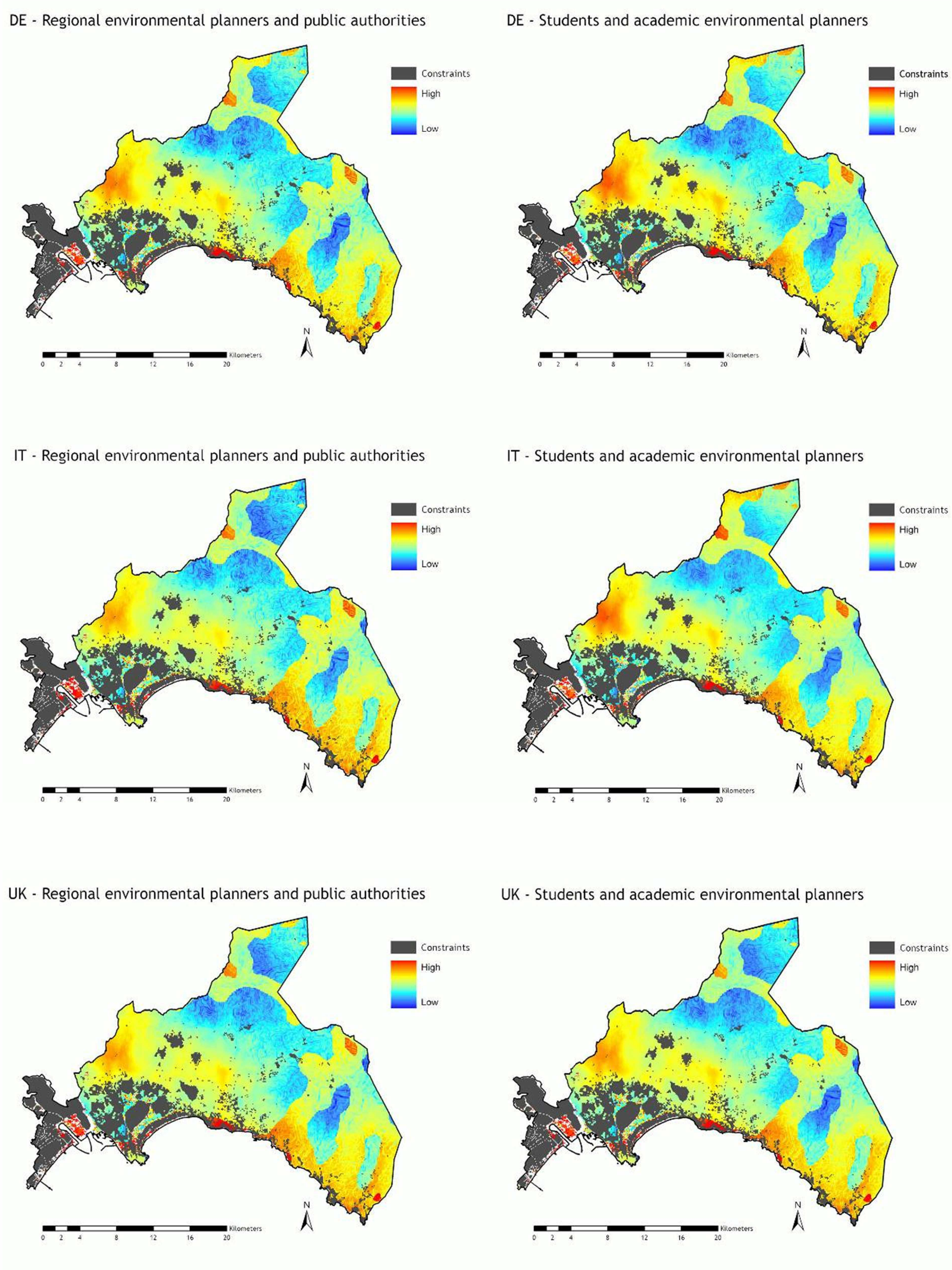


Figure 44: Suitability for housing development with micro wind power plants.
taking into account the wind energy potential and the constraints.

Suitability for housing development with geothermal vertical loops
taking into account the geothermal energy potential and the constraints

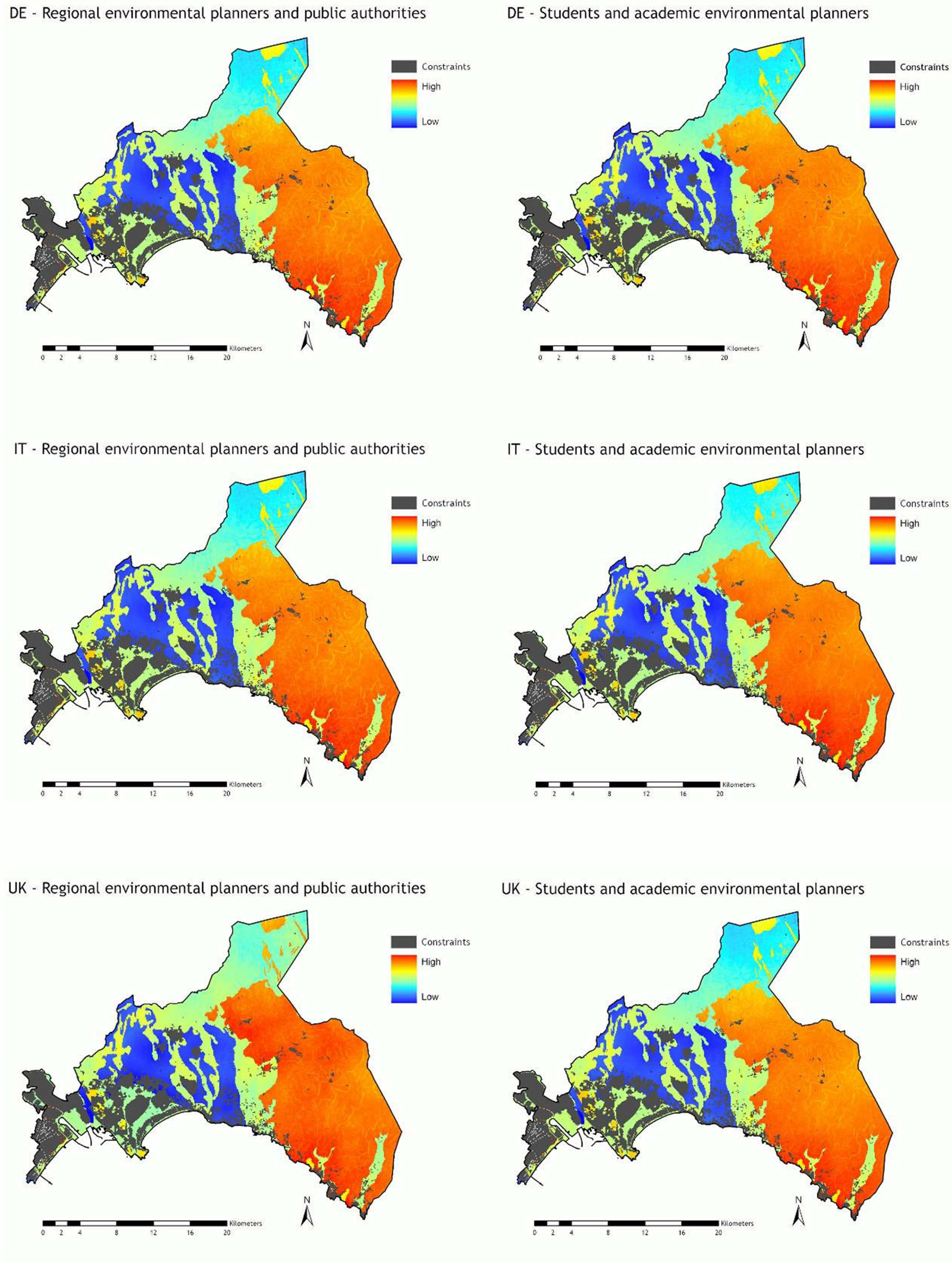


Figure 45: Suitability for housing development with geothermal vertical loops.
taking into account the geothermal energy potential and the constraints.

Suitability for housing development with geothermal horizontal loops
taking into account the geothermal energy potential and the constraints

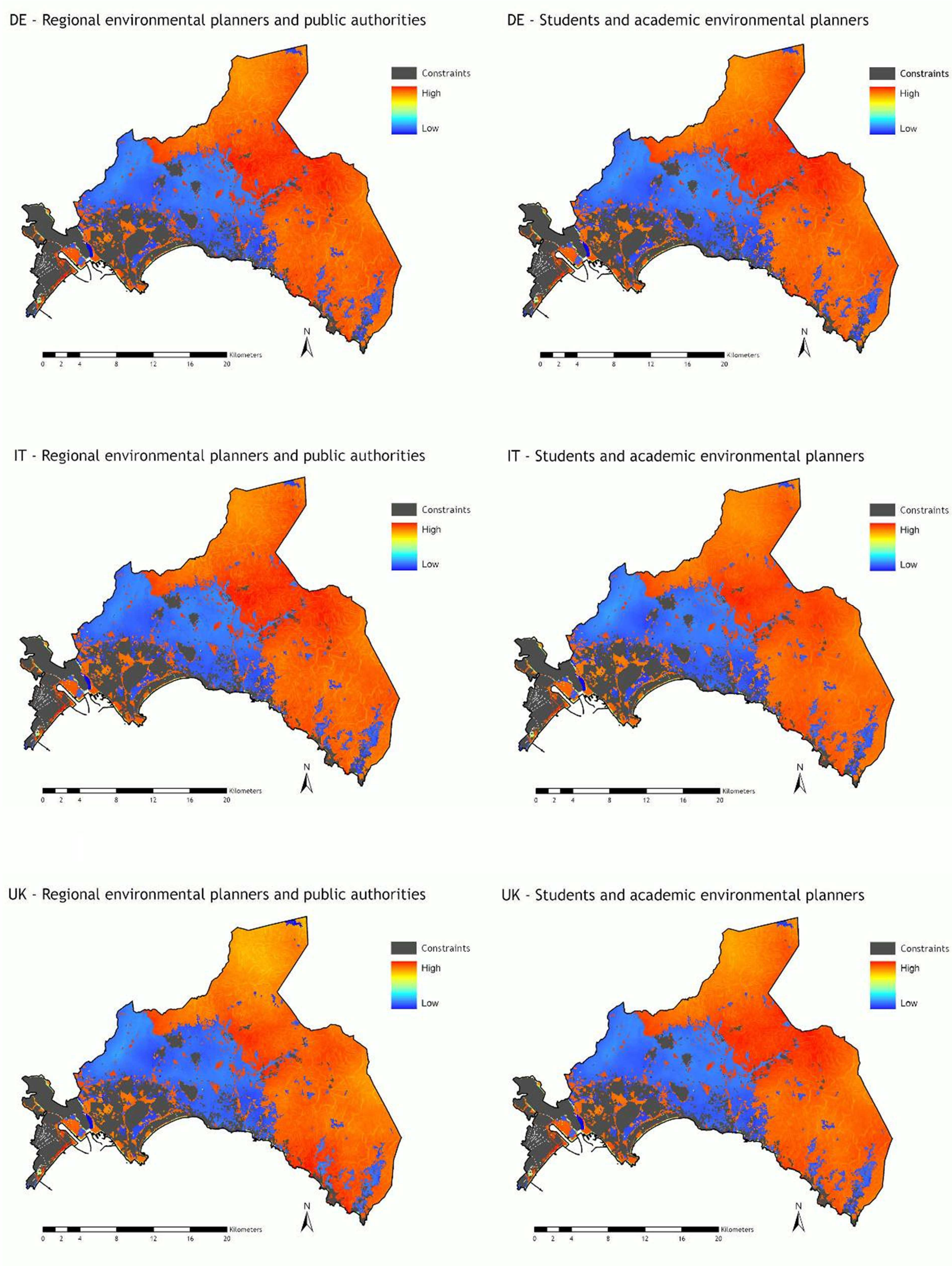


Figure 46: Suitability for housing development with geothermal horizontal loops.
taking into account the geothermal energy potential and the constraints.

Suitability for housing development with micro biomass power plants
taking into account the biomass energy potential and the constraints

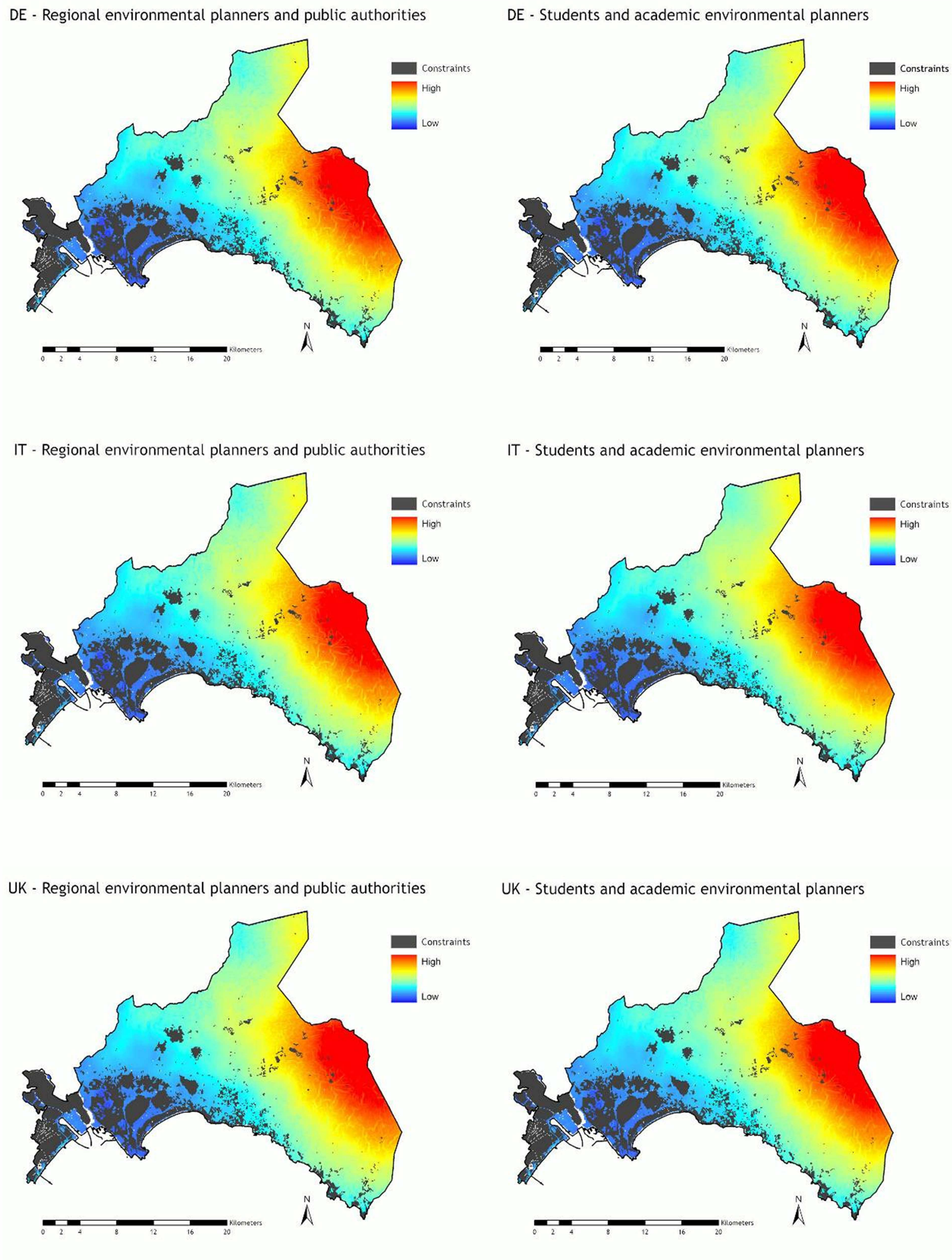


Figure 47: Suitability for housing development with micro biomass power plants taking into account the biomass energy potential and the constraints.

The maps above are the final results of this study. The suitability map for housing development with micro solar power plants, solar energy potential and constraints showed a big variability in the East of the metropolitan area almost on the "Monte Sette Fratelli" Regional Park where the low suitability areas (in blue) were located on the slopes exposed to the north. According to the regional landscape Plan and considering the difficulty to build on those areas, it would be more appropriate to concentrate new urban areas in the locations with a high suitability (in red) on the West of the metropolitan area of Cagliari. For instance, this choice may be the best option according to the proximity to other urban areas and also to roads and services, which already exist.

About the suitability map for housing development with micro wind power plants the localization of new settlement could be identified like for solar energy near Cagliari and surrounded municipalities in the West. There were also other areas on the coastal zone where the potential was very high. In these cases according to the landscape plan's prescriptions and directions, it may be better to invest in micro wind turbines on existing settlement locations.

For all what concerns the suitability for both vertical and horizontal loops, the most suitable locations were situated on the East of the metropolitan area, where for environmental and economic reasons is not convenient to build. However, there were identified also areas for future housing developments with a middle potential near the Cagliari municipality. This may be the best alternative under the consideration of environmental impacts on both wetlands Molentargius and S.Gilla.

The suitability map for housing development with biomass power plants showed similarities with the suitability maps for geothermal energy. The most suitable areas were located in the East, because of the higher biomass potential. More detailed studies and the addition of other criteria such as the costs transportation may be helpful in identifying new settlements location, which from this study appeared to be the areas in yellow. In fact many of them were not inside the regional Park of "Monte Sette-Fratelli", which according to the landscape plan had to be preserved and protected.

In general, these suitability maps gave a first approximation and an "energy efficient direction" for developing scenarios according to experts preferences and micro energy potentials.

Moreover, WLC allowed standardization of the criteria in a continuous fashion, providing for each cell data about the degrees of suitability. Suitability maps are shown in Figures 48-52 and are calculated for each renewable energy in the following order:

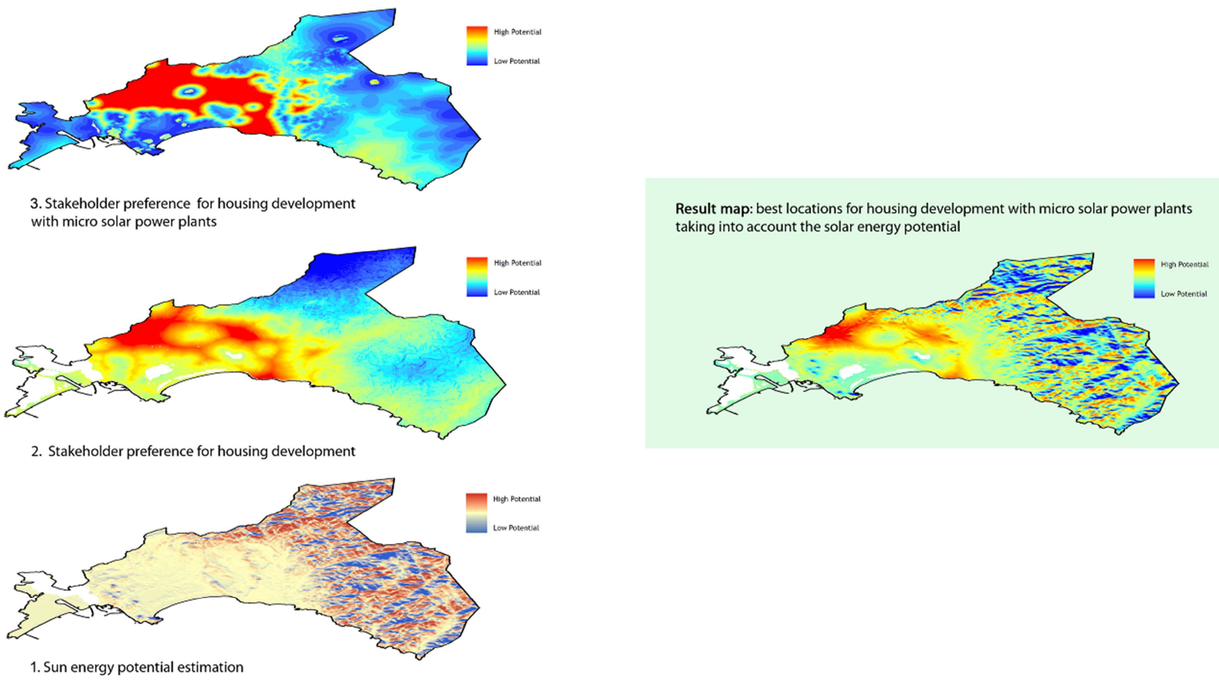


Figure 48: Overlaying layers to obtain the suitability map for housing development with micro solar power plants.

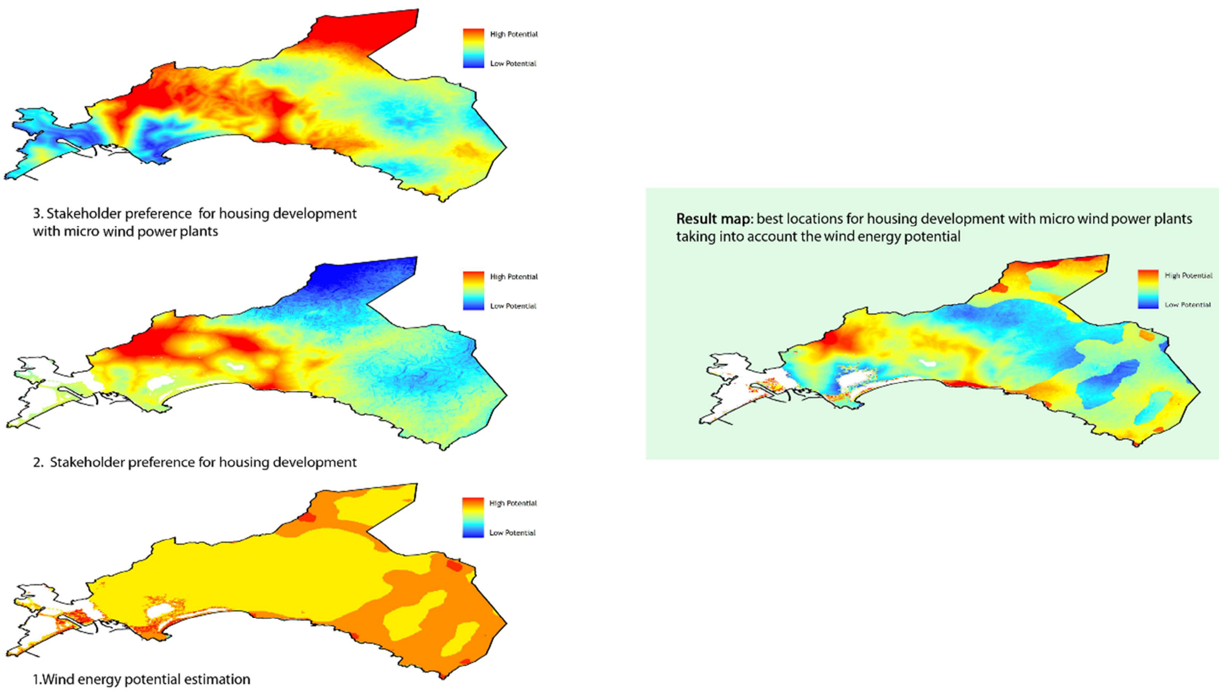


Figure 49: Overlaying layers to obtain the suitability map for housing development with micro wind power plants.

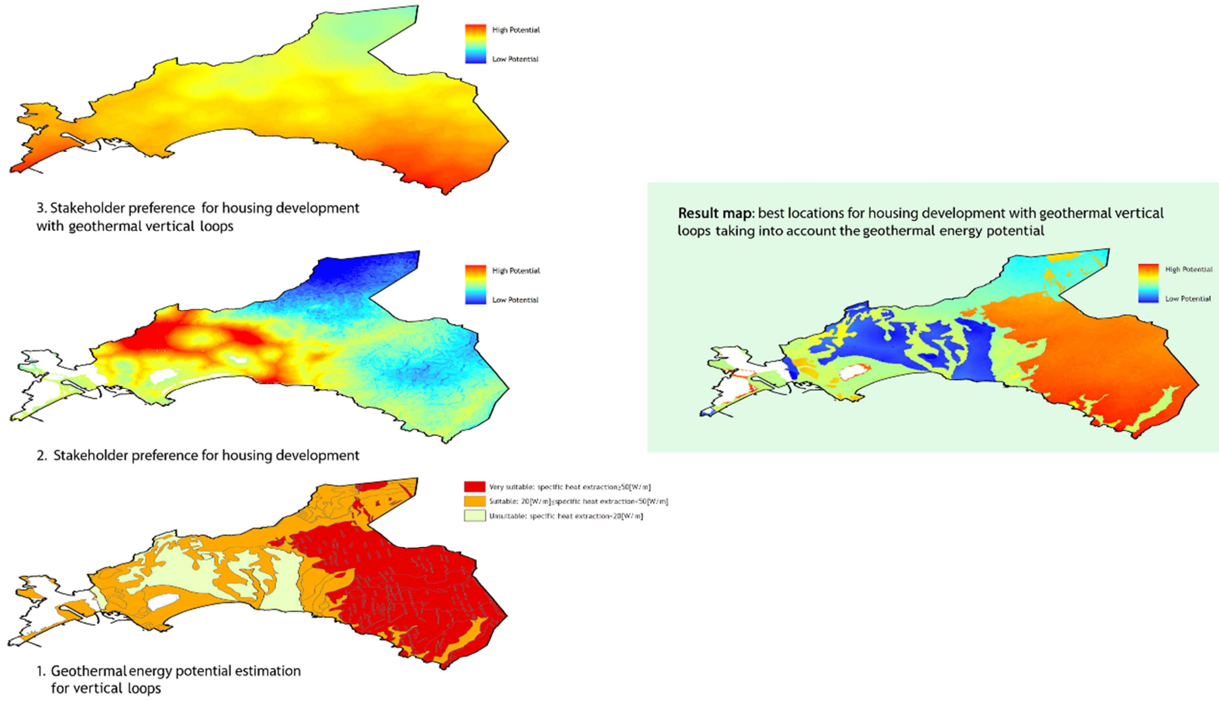


Figure 50: Overlaying layers to obtain the suitability map for housing development with geothermal vertical loops.

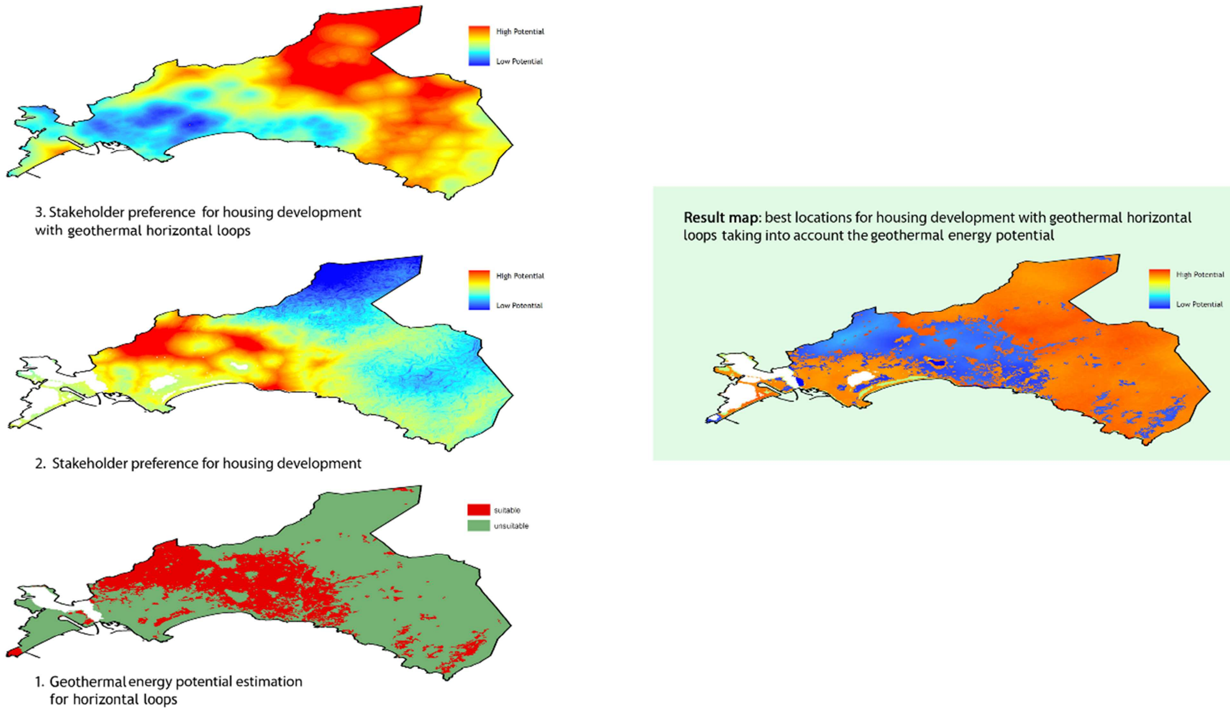


Figure 51: Overlaying layers to obtain the suitability map for housing development with geothermal horizontal loops.

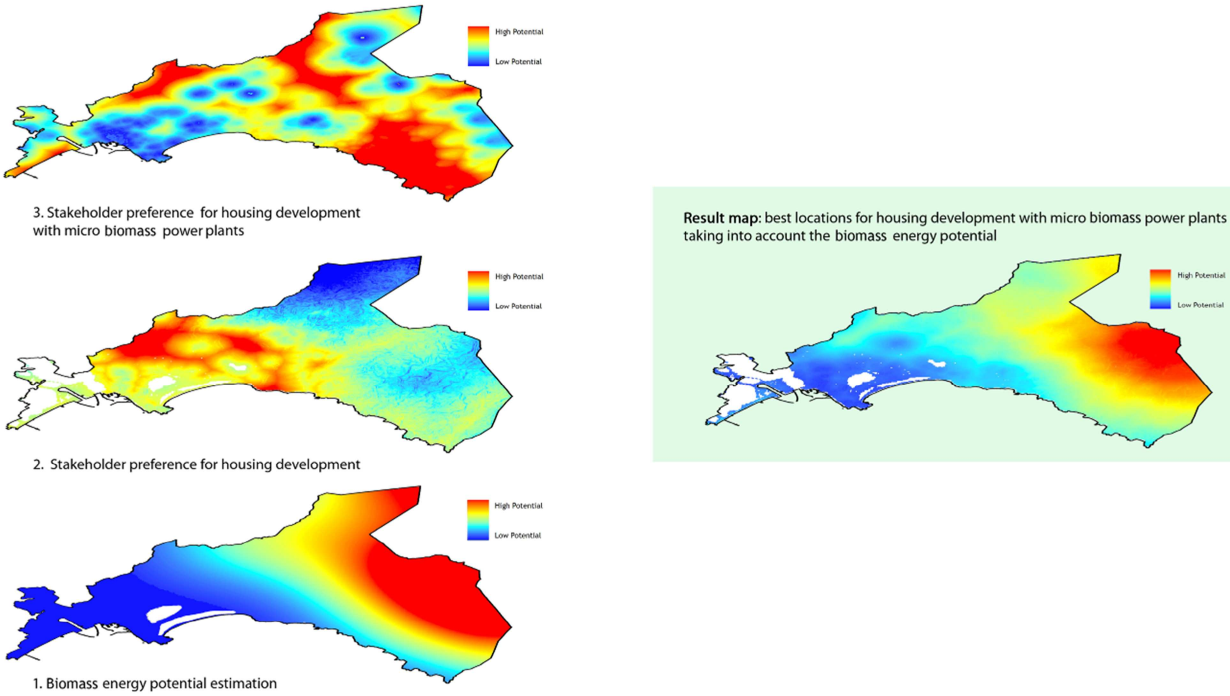


Figure 52: Overlaying layers to obtain the suitability map for housing development with micro biomass power plants.

Furthermore, in the questionnaire was asked if any residential development should take place on environmentally valuable and vulnerable areas, the majority gave a negative answer (see Table 42). So if there were other areas that are valuable or vulnerable but not protected, it would possible to exclude or to consider in more details those areas according to studies conducted at bigger scale.

Expert group		**DE- S.&AP.**	**DE- P.&PA.**	**IT- S.&AP.**	**IT- P.&PA.**	**UK- S.&AP.**	**UK- P.&PA.**
Development on environmentally valuable and vulnerable areas	Yes	-	2	2	2	1	3
	No	14	13	13	19	12	10

Table 42: Expert preferences of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.) about housing development on environmentally valuable and vulnerable areas

On the other hand, other considerations could be included in the planning of new residential areas about the micro renewable technologies. In the questionnaire preferences were asked about locations for wind turbines whether on the roof or in the garden. All stakeholder groups choose the wind turbine on the roof (Tab. 43). In some cases, depending on turbine models a wind turbine on the roof can generate vibration and noise.

Expert group		DE- S.&AP.	DE- P.&PA.	IT- S.&AP.	IT- P.&PA.	UK- S.&AP.	UK- P.&PA.
Wind turbine	on the roof	13	11	12	17	8	9
	in the garden	2	3	2	10	4	4

Table 43: Expert preferences of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.) about the location of micro wind turbine whether on the roofs or in the garden.

In another question was asked about the preference of micro biomass power plants. For the Italian experts and English regional planners and public authorities it is rated almost similar. On the contrary German experts and English students and academic planners prefer the central one (Table 44). A central power plant may be more convenient to provide heat for many houses or many co-generators in every house can be also a good solution for providing electricity and heat. It should be noted that some considerations can be proposed only at bigger scale for the integration of micro biomass power plants in residential areas.

Expert group		DE- S.&AP.	DE- P.&PA.	IT- S.&AP.	IT- P.&PA.	UK- S.&AP.	UK- P.&PA.
Biomass power plant	Single	5	4	6	12	3	6
	Central	10	10	7	12	11	6

Table 44: Expert preferences about types of micro biomass power plants (single or central).

Furthermore, experts expressed similar or different preferences about the integration of micro technologies for heat and electricity production. Italian experts, English and German academic planners like solar panels and solar thermal collectors. On the contrary, German preferred solar panels and geothermal vertical or horizontal loops, while English environmental planners choose solar panels and geothermal horizontal loops (see Table 45, Figures 53-54-55).

Here should be noted that micro solar power plants were the most preferred technology. It may be depend on the confidence/acceptance with this technology. On the other hand, geothermal power plants were selected, because they were considered very efficient and with low environmental and landscape impacts. For instance, the main reason was that people highly regard aesthetics therefore those technologies with least visual impact would be more accepted. On the contrary experts, who preferred solar power plants explained that this kind of technologies were cheaper to construct initially and considered more reliable for the energy resource almost everywhere. Furthermore, for solar power plants it was expressed that no time is requested for constructing the power sources for example digging and putting in place the pipes for geothermal power. Biomass power plants was a second choice in Germany for larger schemes, as they have been found to be efficient, if they combine heat and power.

Expert group		**DE-ac.pl.**	**DE-en.pl.**	**IT-ac.pl.**	**IT-en.pl.**	**UK-ac.pl.**	**UK-en.pl.**
Preferences	Electricity	SP	SP	SP	SP	SP	SP
	Heat	STC	GVL/GHL	STC	STC	STC	GHL

Table 45: Expert preferences about the integration of micro technologies for heat and electricity production.

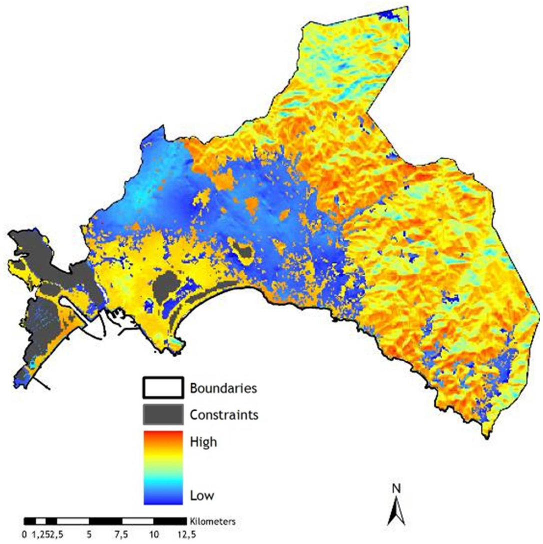


Figure 53

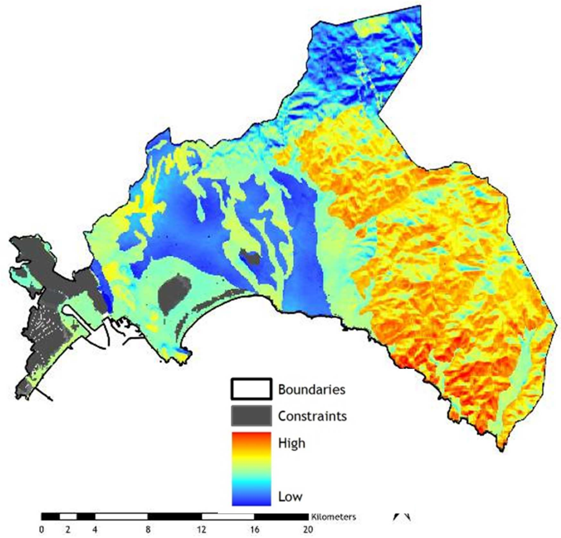
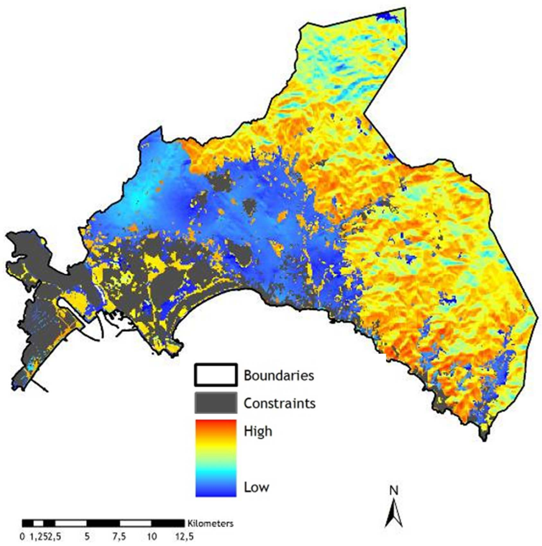


Figure 54



German regional planners and public authorities
Figure 53: Suitability for housing development with geothermal horizontal loops and solar power plants taking into account the geothermal energy potential and constraints (water, built-up areas, flooding and landslides areas).
Figure 54: Suitability for housing development with geothermal vertical loops and solar power plants taking into account the geothermal energy potential and constraints (water, built-up areas, flooding and landslides areas).

English regional planners and public authorities
Figure 55: Suitability for housing development with geothermal horizontal loops and solar power plants taking into account the geothermal energy potential and constraints (water, built-up areas, flooding and landslides areas).
Figure 55

The last question in the questionnaire was about the visualization of all micro renewable technologies with a project proposal of an energy efficient residential development showing the visual impact of those micro power plants. For the majority it was helpful to have that kind of visualization (Figure 52). The main reasons were that it helped to show the scale of the different types of renewable energy generation technologies and integrated the ideas in a way that was more intuitive to understand. However, the responses got in the questionnaire may depend upon how each are visualized, especially for people who are less clear on the technology. According to this, it should be highlighted that the participants were not evaluated on knowledge about micro renewable technologies. The visualization was also useful e.g. with residential wind turbines where photos of such settlements may not currently be available.

Figure 56 presented results about the visualization from experts perspectives.

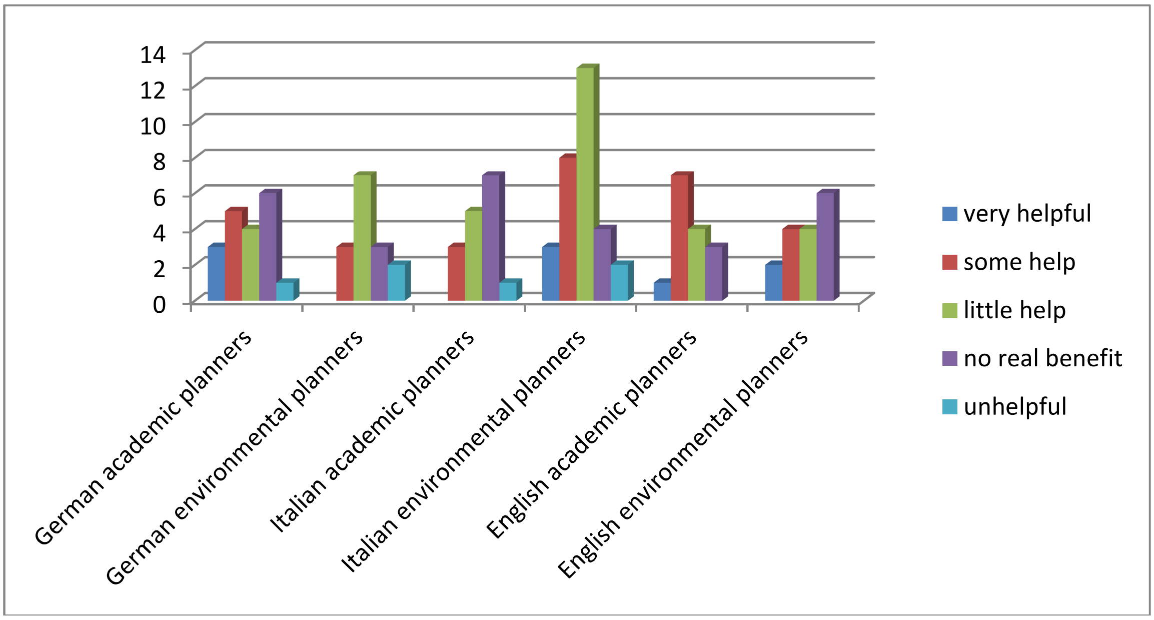


Figure 56: Experts opinions about the integration of visualization in the questionnaire.

Some participants wanted to find in the questionnaire a brief explanation on how the technologies work and their advantages and disadvantages, but it was decided in developing the questionnaire that an explanation about the different technologies and environmental impacts could influence the experts opinion. Therefore, it was preferred to show only how the power plants looked like in a residential development.

6. Discussion

The integration, in urban and regional planning, of alternative power sources can play a key part in reducing a region's dependence on external fuels. Micro-generation technologies (such as wind, solar, biomass and geothermal) can provide a significant source of renewable and environmentally friendly energy in new residential areas. Urban and regional planning can optimize this integration by selecting the best suited areas with the highest energy potential and least environmental impacts, in addition to choosing the best mix of renewables for each individual residential site. This thesis suggested a methodology for identifying the best locations for new housing developments which utilize micro-renewable technologies. Decisions regarding the best energy mix for different residential areas can be supported by the maps compiled as part of this work. The proposed approach was based on the assessment of energy potential and other, expert weighted, preference criteria. The approach was implemented in GIS because of its capacity to integrate information into a spatial context and its potential to support the decision-making process. GIS can help decision-makers in evaluating the most energy efficient alternatives by providing a visual representation of choices. However, only planners and decision-making authorities have full access to GIS, while there are very few spatial planning tools available to the general public. The main challenges of GIS-based spatial decision-making applications lie in bridging the gap between expert and public users in order to provide a system for enhancing public participation. GIS capabilities with multi-criteria decision analysis can provide a means towards achieving this goal.

6.1 Data availability and accuracy

The accuracy in finding the most and least technically suitable locations was dependent on the accuracy of input data. The data used in this work was obtained from different sources with different levels of accuracy. The errors from any one map layer may have propagated through the analysis and, combined with errors from other layers, may have caused inaccuracies in output maps. Therefore, the resulting maps were less accurate than the least accurate layer used in their composition. As methods have been successfully tested under German and Italian data conditions, it may be assumed that they can be applied in other European countries.

In Tables 46 and 47, different data for the estimation of the energy potentials is shown.

Italian Data			
Energies	**Data**	**Scale/Units**	**Data origin**
Sun	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Local irradiation time	Day	GRASS GIS
	Linke atmospheric turbidity	Dimensionless	GRASS GIS manual
	Ground albedo	Dimensionless	
Wind	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Wind speeds 25 m	m/s	Aeolic Italian Atlas (Atlante eolico italiano)
Geothermal	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Geological Map	1:200.000	Earth Science Department of Cagliari University
Biomass	Land use	1:25.000	Region of Sardinia
	Protected areas Natura 2000 Sites	1:10.000	Landscape Plan of Sardinia

Table 46: Italian Data.

German Data			
Energies	**Data**	**Scale/Units**	**Data origin**
Sun	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information

	Local irradiation time	Day	GRASS GIS
	Linke atmospheric turbidity	Dimensionless	GRASS GIS manual
	Ground albedo	Dimensionless	
Wind	Digital Elevation Model DEM 90	90x90 m	CGIAR Consortium for Spatial Information
	Wind speeds 10 m	dm/s	German Weather Service (Deutscher Wetterdienst)
Geothermal	Digital Elevation Model DEM 50	50x50 m	State Office for Mining, Energy and Geology ("Landesamt für Bergbau, Energie und Geologie", LBEC)
	Quaternary Geological Map	1:500.000	
	Tertiary and Quaternary Geological Map	1:100.000	
Biomass	Land use	1:100.000	European Environment Agency (CORINE Land Cover 2000-Program)
	Protected areas Natura 2000 Sites	Shape-Files	Ministry of Lower Saxony for environment and climate protection („Niedersächsisches Ministerium für Umwelt und Klimaschutz")

Table 47: German Data**.**

For the estimation of solar energy potential, data with the same accuracy level for both the Region of Hannover and the Eastern Metropolitan Area of Cagliari was used. The calculation of the solar energy potential estimation depended on the application of the *r.sun* model and on the *PVGIS* data, which means that it could be applied in other regions. However, the accuracy of the results depends on input data (DEM) and on *PVGIS,* or other measured data availability. The *r.sun* model can also estimate solar energy potential in terms of solar irradiance [W.m^{-2}] or solar irradiation [Wh.m^{-2}.day^{-1}] on solar panels. This could be utilized on a larger scale for estimations on a 3D city model.

The data regarding wind speed presented different challenges. The biggest difference between German and Italian wind speed data was the height of calculation. German data was calculated at 10 m height above ground level, while Italian data was calculated at 25 m height. Wind speeds were also obtained using different methods: The German Weather Service used the Statistical wind field model ("Statistische Windfeldmodell"), a regression model which takes into account parameters like such as height above sea level, geographical location, topography and land cover, while Italian data was derived from the database of the Italian Wind Atlas ("Atlante eolico italiano"), which used a wind flow model (WINDS, Wind-field Interpolation by Non-Divergent Schemes), or the so-called mass-consistent model, based on the equation of mass conservation, or continuity.

In this study, factors such as roughness, height above sea level and geographical location were also considered in the estimation of average annual wind speeds. Wind speeds provide a good approximation of wind energy potential; wind speed flow simulations can be useful in the planning of new settlements.

In terms of geothermal energy, potential maps for horizontal loops were required to be created only for the Sardinian case study, as the potential map for horizontal loops for Lower Saxony was previously available. The accuracy of geothermal energy estimation was dependent on data availability (e.g. profiles) regarding subterranean rock layers, for geothermal vertical loops, and rocks in the region of up to 1.3 m, for geothermal horizontal loops. The study demonstrated that despite the current insufficiency of data regarding stratification and soil characteristics, the information needed can be generated by the assistance of geologists with local knowledge. Expert consultation was necessary in both Lower Saxony and Sardinia for the development of the geothermal potential maps for vertical loops. In Sardinia, the experts were also asked to compensate some deficiencies where maps were missing for the whole case study area. Additional site-specific studies and local analyses are required to yield more precise results for the planning and design of horizontal loops. The Region of Sardinia has recently developed a geological map, at 1:20.000 scale, which may aid in further research to obtain a more accurate geothermal energy potential estimation.

Moreover, more detailed data about groundwater levels and movements is important to estimate the geothermal energy potential using groundwater flow. Despite the unavailability of detailed maps depicting geothermal resources of the area, it is reasonable to assume that the area contains good geothermal potential due to the presence of subsoil aquifers and vast lagoons (RANIERI & PIRODDI 2009). From a functional system and architectural perspective, geothermal systems are particularly suited for application as renewable energy sources as they do not require any particular environmental condition. Geothermal energy sources may also offer the opportunities of fossil fuel independence, potential for autonomous decisions regarding energy policy and the development of economically competitive technologies (ibid.). The Cagliari metropolitan area has diverse potential for geothermal resource use: It may choose to utilize the superficial low enthalpy waters for newly built or existing single buildings, research medium enthalpy conditions or exploit current favorable areas, and construct remote heating systems for mid-size user communities.

For the biomass energy potential estimation, different data was used for Lower Saxony and Sardinia. There were some difficulties in obtaining the forested area data in Lower Saxony. As it was not available for the entire area under consideration, we decided to use the data from the Land Cover Corine, at 1:100.000 scale. In Sardinia, the data from the Regional Landscape Plan, which covered the whole area under consideration, at 1:25.000 scale, was used.

Biomass potential estimation can be calculated in any region. The only data required is that pertaining to forested areas which are available for biomass use. Other data, which needs to be estimated, are the wood extraction capacity and transportation costs.

6.2 Weighting, experts preferences and methodology

Expert weighting of criteria regarding locating new energy efficient residential development, in combination with the use of GIS and multi-criteria analysis, may be useful for supporting the complex planning process. A number of experts surveyed, independently came to express significantly similar preferences.

The results of the research indicate that this method can incorporate different levels of complexity of decision problems. Housing development in close proximity to the city of Cagliari and surrounding municipalities was favoured by expert preferences.

The wetlands of Santa Gilla and Molentargius, located in the vicinity of the city of Cagliari, impact on the micro-climate and affect the urban life quality around them (cf. ZOPPI 2009). The close dependence between the health of wetlands and the quality of life of settled communities highlights the need to ensure their protection. Therefore, more detailed study, on a larger scale, in relation to the environmental and landscape impact on these wetlands will be needed.

It must be noted that the method proposed is only a tool intended to aid decision-makers in reaching a decision, not a suggestion for the decision itself. The selection of possible locations for new housing development with micro-renewables was dependent on several factors with differing spatial variability. Factors were standardized to a continuous scale of suitability and weighted according to their relative importance. The relative importance of the weights of factors was estimated using the analytical hierarchy process (AHP). Constraints were defined as a Boolean mask. The land evaluation was performed on a cell by cell basis. Weighted Linear Combination allows each factor to display its potential because it takes into account factor weights. It is important that factor weights are chosen correctly in WLC as they determine how individual factors will aggregate. The advantage of this method is that all factors contribute to the solution based on their importance. The aggregation of individual weights is prone to be subjective, even when pairwise comparison is used for ensuring consistent weights. A limitation using comparison matrices is that if there are too many criteria (e.g. more than 7 for each matrix), the matrix will often be inconsistent due to the difficulty of experts in expressing “consistent” opinions by comparing too much criteria. Thus, the choice of factors played a crucial role. Selecting a set of criteria, for example “proximity to urban areas”, means not managing urban sprawl and its negative effects on the environment, such as air pollution, noise and the consumption of natural resources. On one hand, the consideration of this criteria by creating suitability maps for new settlements, limited the development of diffuse built-up patterns which were too sparse and located at a greater distance from centers. On the other hand, the criteria “distance from environmentally valuable areas” reduced fragmentation of the country side through the preservation of biodiversity.

Housing selection is an important issue in urban planning for growing urban areas. Because of the complexity of site selection, the identification of appropriate residential areas requires consideration of multiple alternative solutions and evaluation criteria. The criteria selected for housing development and micro-renewable preferences need to be combined with other criteria, depending on analysis conducted at a smaller scale. The proposed method offers a number of advantages over classical site suitability analysis techniques. First, it provides a structured approach to derive the suitability by deconstructing a complex problem into three levels: energy potentials, expert preferences for housing development, and expert preferences for housing development with micro-generation technologies. This allows planners and public authorities to focus on a systematic analysis of the factors for each level. A disadvantage is that the criteria are less differentiated than in a conventional environmental impact or suitability assessment. Supplementing the criteria also requires considerable effort. Second, this method allows the incorporation of criteria, which differ in nature, and provides decision-makers with the opportunity to enter their own judgments. Third, the approach is transparent and suitable to weighting of different criteria in the case where no democratic legalized standards are available as a basis for weighting and decision-making. Fourth, the general preference, and not a site-specific interest, is relevant, which may help support rational decisions and achieve good decision acceptance, especially in local development. Fifth, if regional /local stakeholder preferences are taken as a basis, the method can be used to model the probable future expansion of housing development according to local interests. If mandatory zoning is weak, or non-existent, land use planning can utilise this information for strategy building. Sixth, given that stakeholders involved are given the same weight, the model may support better communication between decision-makers and the community. In representative democracies, decisions regarding land use planning need to be made by the elected representatives within the limits of the legal framework. In this case, the views of special interest groups should be considered at the start of the decision-making process.

In the future, more concrete legal standards and priorities for decisions about energy efficient housing and the environment may greatly restrict the importance of expert preferences. In that case, more predefined priorities can be included in the method, in addition to a combination that includes conventional impact assessment.

Environmental planners and public authorities often make complex decisions within a short period of time, during which they must take into account sustainable development and participation. A set of land-use suitability maps (e.g. as part of a landscape plan) would be useful for supporting decision-makers in reaching decisions faster. Once the maps are made available, planners could analyze any new project by using simple operations, such as map overlays or statistical analyses, on a given area. In this study, this approach led to the identification of conflicting demands, in addition to sites with the highest energy potential and lowest environmental and landscape impacts. The development of land suitability maps also presents an opportunity for all governmental departments involved in land management to compare their respective perspectives and coordinate their policies. Ideally, these maps should incorporate complex criteria, integrating several stakeholder points of view. Selecting or adding criteria from a list of factors should be a negotiation between actors.

7. Conclusion

This thesis presented a contribution to the disciplinary debate, with reference to energy efficiency, on the evaluation of urban sustainability. The thesis provided a detailed description of a proposed method and its implementation in a GIS environment. Energy potential estimations and a spatial multicriteria decision making (SMCDM) process based on GIS techniques were the main tasks of the work. The method suggests the consideration of several criteria by using multi-criteria analysis for new housing development and integration of micro renewable technology as it is comprehensive, flexible and can be modified to fulfill national and regional needs. The case study area, where the recommendations were tested for implementation, was the Eastern Metropolitan Area of Cagliari in the South of Sardinia. Its main purpose was to suggest the best areas for residential development in the tested area.

It was shown that the estimation of potential renewable energy is achievable with currently available methods, except in the case of biomass potential. Although the proposed approach for estimating micro renewable energy potential at regional/sub-regional scale is still under improvement, the preliminary results encourage continuing research in this direction. From an operational point of view, the research has experimented with the application of several methods, datasets and software packages, to calculate potential renewable energy for new settlements. For the case study area, it was assumed that all three layers (energy potential, new settlement preferences and micro renewable preferences) were of equal importance and therefore carried the same weight in consideration. However, it would also be possible to grant more consideration to energy potential, if desired. This flexibility of the proposed approach renders it useful as a planning tool. Moreover, users can employ their individual local, national and regional expertise in the decision-making process. Such a framework allows the integration and the adaptation of both qualitative and quantitative criteria for assessing site suitability. Additional layers of information, such as economic considerations, could easily be integrated into the approach and, consequently, be taken into consideration when locating new energy efficient residential areas.

The use of GIS and Multi-criteria analysis were useful in achieving the desired outcomes and, as such, reducing the complex nature of the planning process by allowing different stakeholders to identify scenarios for supporting decision making. GIS technology offers data acquisition, storage, retrieval, manipulation, and data analysis to develop information which supports the decision-making process. The MCDM technique provides the tools for integrating the geographical data and the decision maker's preferences into a one-dimensional value array of alternative decisions. In this work, several advantages of using the Analytic Hierarchy Process (AHP) as a tool, in conjunction with suitability maps, have been highlighted and some of its shortcomings and modifications have been briefly illustrated. Rather than following a negative planning approach, the AHP helps decision-makers in partaking in positive planning by including expert opinions at the beginning of the planning process. In this context, in order to find the best locations for new settlement development, AHP aids decision-makers by providing a comprehensive and rational framework for structuring a decision problem, representing and quantifying priorities, relating different criteria to overall objectives and evaluating alternative scenarios.

In its application, the AHP has been used for capturing the perceptions of stakeholders on the environmental and landscape impacts of each micro renewable technology for future housing development. This may be helpful for public authorities in prioritizing their land use or development plans. Therefore, the AHP can be a useful tool for systematically analyzing the opinions of several groups of experts belonging to diverse fields.

Moreover, the method allows planners and planning authorities to plan alternative settlements based on "non-traditional criteria," evaluating the ecological, social and economic impact of each proposal. During the process, the weighting of views of all interest groups could be conducted with respect to their level of involvement. Thus, this model can increase public participation in urban decision-making and alternatives could be constructed which take into consideration information from several sources: the participatory process, the review of the projects and technical interviews, for example.

This approach can be applied in developed and developing countries. Unplanned physical growth is one the most challenging problems in developing countries. It imposes many socio-economic and environmental constraints. Therefore, the physical growth of cities should be guided and controlled by considering the different parameters which influence city expansion. In Europe, in particular, there is a need for tools that assist regional/urban planners and public authorities in managing the growing complexity of rapidly evolving cities. Such an integrated city planning tool can be helpful in monitoring progress in the development of a city in relation to its regional environment, developing long-term visions for the city and, finally, in formulating integrated city policies. On the other hand, such a planning tool is only a means, and not a goal in itself.

Managing a city requires a large amount of data and information which traditional methods are unable to provide. This model is easily modifiable to accept new data as it comes to light.

Furthermore, better results will be achieved if the process is carried out iteratively, giving the participants a chance to view the energy potential maps and to identify the best locations. In order to improve on criteria accuracy, smaller units with more detailed data may considerably improve the results.

In the future, the methodology could be improved at local scale, in particular:

- Estimation of solar energy potential for urban areas using a three-dimensional (3D) city model. In urban installations, PV electricity comes from a large number of small power generators that should be distributed over an area. Therefore, the assessment of PV potential requires a detailed analysis of buildings and surfaces that are available for the installation of PV modules. For this purpose, it would be necessary to develop sophisticated modeling tools and spatial data representing the complexity of the urban environment. For instance, the 3D city model of urban areas could be implemented in a GIS database.
- Simulation of wind flow in the urban context for wind energy estimation. Numerical simulation of air flow distribution in a built-up area is an effective way to analyze and predict the urban thermal environment. Urban areas are known to be warmer (urban heat islands) than surrounding rural areas due to anthropogenic heat releases and modifications of soil surfaces. Buildings block air flows, and air flows are accelerated in building corridors. Urban areas contribute significantly to the modification of microclimate. Numerical approaches should be considered to incorporate urban effects into numerical models to simulate air flows around buildings under the influence of wind variations.
- For future improvements of geothermal energy potential, the new geological map, on a scale of 1:20.000 which was recently developed by the Region of Sardinia and provides estimates of groundwater movement, can be helpful in obtaining a more accurate estimation at a larger scale. Furthermore, geothermal maps will be more accurate by providing additional parameters such as thermal and heat conductivity, borehole thermal resistance and including more information about geology, hydrogeology and geochemistry. This will aid in providing information about formations groundwater parameters (pore volume, pressure head, trasmissivity), groundwater quality of aquifers (salt/sweet, pH, methane), geomorphology, stability of slopes, surface and subsurface drainage. The in-situ geothermal response test provides data on the thermal properties of the ground, the thermal conductivity and borehole resistance, for example.

- The next step for biomass potential may be the mapping of different forest biotopes. The Region of Sardinia has already mapped the conifers over its region for producing wood, which has been used for heat production in a power plant in Ottana, province of Nuoro. There are currently no programs or plans to use the biomass at a small scale to heat and power homes (e.g. co-generators). Future improvements of biomass potential estimation will require an accurate estimation of the biomass resource and the development of new methodologies for the estimation of wood extraction capacity and transportation costs for a hypothetical settlement which could also be implemented in a GIS environment.

The suitability maps obtained and developed can be integrated into one map depicting the best locations for new settlement development according to the more appropriate energy mix for the area under consideration.

The regional energy environmental plan of Sardinia ("Piano energetico ambientale regionale", PEARS) integrates the content and objectives of energy planning at higher-level and indicates the main environmental protection objectives (minimization of landscape alteration and environmental interventions) and the diversification of energy sources (equal mix of sources taking into account the needs of consumers, environmental protection and the development of new sources and technologies). The plan was expected to provide 550 MW wind, 150 MW biomass, 100 MW solar photovoltaic and 80 MW solar thermal power by 2010. Future locations for installations are to be selected in accordance with the Regional Landscape Plan which recognizes the regional specific components of the landscape and the landscape types which connect the fabric of the different landscape areas. On the basis of the relevance and integrity of the different components of the landscape, different levels of values are to be identified ranging from unmodified to compromised landscapes. Accordingly, quality objectives such as preservation, processing and retrieval, which are associated with the corresponding measures, should be introduced before designating new residential development with micro renewable technologies.

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ANNEX 1: Questionnaire

Contact:
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As part of my PhD research I am examining the integration of micro renewable energy technologies in new settlements. In this particular part of my study I am surveying the opinions of environmental experts and planners. Please help me by completing the following questionnaire and email it back to palmas@unica.it.
The boxes in the questionnaire can be activated (ticked) by double click.
Expert stakeholder groups
(please select one of these options)

☐ *Students and academic environmental planners*

☐ *Regional environmental planners and public authorities*

Please indicate below if you would regard yourself as particularly expert on any of the following sectors:

- ☐ *Wind Turbines*
- ☐ *Solar panels*
- ☐ *Solar Thermal Collectors*
- ☐ *Biomass Power Plants*
- ☐ *Geothermal Vertical Loops*
- ☐ *Geothermal Horizontal Loops*

University/Institution: ……………………………………………………………………………………………………….

Date……………………………………… Location…………………………………………………………

As part of my PhD research I have developed a framework for producing suitability maps for micro renewable potentials. In this questionnaire I am examining the evaluation of experts in Italy, Germany and United Kingdom to the use of micro-scale renewable energy generation technologies integrated in new residential settlements. These types of decentralized production systems, with their potential gains in energy efficiency, are likely to be suitable for meeting future objectives regarding energy security and reduced greenhouse gas emissions in Europe.

To examine these issues I am using a method of multi-criteria evaluation, known as pairwise comparison, which asks stakeholders to compare pairs of factors (criteria) using the scale shown below.

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT

MORE IMPORTANT

HOW TO ANSWER THE QUESTIONS- EXAMPLE

As an example, in the matrix below each row factor is compared to the column factor, using the scale from -4 to +4. For instance, in terms of the suitability of land for new housing development the proximity to existing urban areas is considered as MODERATELY LESS IMPORTANT than the slope gradient. Similarly, the proximity to existing urban areas is rated as MODERATELY MORE IMPORTANT than the distance from wetlands, forests and protected areas and the slope gradient is evaluated as STRONGLY MORE IMPORTANT than the distance from wetlands, forests and protected areas.

Q: How do you evaluate the three criteria below if you have to plan new residential areas?

Evaluation of row factor relative to column one.	Proximity to existing urban areas	Slope gradient	Distance from wetlands, forest and protected areas
Proximity to existing urban areas		-1	1
Slope gradient			2
Distance from wetlands, forest and protected areas			

NB: a positive sign indicates a major importance of the row factor compared to the column one.

Please pay attention to the following in completing this questionnaire:

- The following questions will first give you the opportunity to assess the suitability of areas for new settlements and then evaluate the appropriateness of locations for different renewable energy generation technologies.
- Your thoughts and opinions on the different options and methods of presenting information will be valuable for my research which ultimately aims to provide a stronger basis for including renewable energy issues in settlement and regional planning.
- Your particular opinions will not be disclosed in my work. Let me know if I should be particularly sensitive in communication of the topics you discuss, and how the information should be treated.

Part I: Locating new settlements

Please rate each pair of factors below in terms of their relative importance according to your preferences of a spatial planner for identifying locations for new settlements without regard to micro renewable technologies. Please remember to rate each row factor relative to the column one.

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

← LESS IMPORTANT MORE IMPORTANT→

Do you think that any residential development should take place on environmentally valuable and vulnerable areas?

☐ Yes ☐ No

Imagine having to plan new residential areas. To decide where to locate new residential areas there are five criteria. Please indicate your preference by comparing each row factor with the column one.

Evaluation of row factor relative to column one.	Proximity to existing urban areas	Proximity to major roads and train lines	Distance from environmentally valuable and vulnerable areas or from protected areas	Proximity to water (sea, lakes and rivers) [attractiveness]	Slope gradient
Proximity to existing urban areas					
Proximity to major roads and train lines					
Distance from environmentally valuable and vulnerable areas or from protected areas					
Proximity to water (sea, lakes and rivers) [attractiveness]					
Slope gradient					

NB: a positive sign indicates a major importance of the row factor compared to the column one.

Part II: Locating renewable energy generation

The visualization below shows features of an energy residential efficient development and the visual impact of the power plants. A larger version is available separately in Annex 1.

The following questions concern different methods of micro-scale renewable energy generation. For every method please rate each pair of factors using the scale below in terms of their relative importance for identifying sites where the generation method would be most appropriate. Please remember to rate each row factor relative to the column one.

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

← LESS IMPORTANT MORE IMPORTANT→

New settlement with household wind turbines

Which power option do you prefer?

☐ wind turbine on roof a)

☐ wind turbine in garden b)

a)

b)

For your chosen option evaluate the criteria below.

Q (WT): How do you rate the importance of the following criteria against each other?

Evaluation of row factor relative to column one.	Distance from historic/ cultural features	Distance from Special Protection Areas (Natura 2000 sites) and others avifaunistic important areas	Distance from other protected areas and of high landscape esthetic
Distance from historic/cultural features (historical centre, areas of historical and cultural interests, archaeological sites, etc..)			
Distance from Special Protection Areas (Natura 2000 sites) and others avifaunistic important areas			
Distance from other protected areas and of high landscape esthetic			

NB: a positive sign indicates a major importance of the row factor compared to the column one.

New settlement with solar photovoltaics and/or solar thermal collectors

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

← LESS IMPORTANT MORE IMPORTANT→

Q (SP or STC): How do you rate the importance of the following criteria against each other?

Comparison between..	Distance from landscape protected areas and other beauty areas	Distance from historic/cultural facilities
Distance from landscape protected areas and other beauty areas		
Distance from historic/cultural facilities (historical centre, areas of		

historical and cultural interests, archeological sites)		

NB: a positive sign indicates a major importance of the row factor compared to the column one.

Biomass Power Plants

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

← LESS IMPORTANT MORE IMPORTANT→

Which power option do you prefer?

☐ central power plant (for many houses) a)

☐ single power plant b)

For your chosen option evaluate the criteria below.

Q (B): How do you rate the importance of the following criteria against each other?

a) **b)**

Comparison between..	Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	Distance from landscape protected areas or other beauty areas
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)		
Distance from landscape protected areas or other beauty areas		

NB: a positive sign indicates a major importance of the row factor compared to the column one.

Geothermal Vertical Loops

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

← LESS IMPORTANT MORE IMPORTANT→

Q (GVL): How do you rate the importance of the following criteria against each other?

Comparison between..	Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	Proximity to drinking water or aquifers
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)		
Distance from drinking water or aquifers		

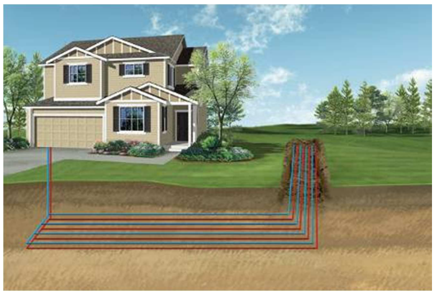
NB: a positive sign indicates a major importance of the row factor compared to the column one.

Geothermal Horizontal Loops

-4	-3	-2	-1	0	1	2	3	4
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

← LESS IMPORTANT MORE IMPORTANT→

Q (GHL): How do you rate the importance of the following criteria against each other?



Comparison between..	Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	Proximity to flooding areas
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)		
Distance from flooding areas		

NB: a positive sign indicates a major importance of the row factor compared to the column one.

If you think that other criteria for each renewable technology are missing, please add them here and state why those criteria are important from your perspective. You can also use the comparison matrix if you want.

PART III: Preferences for micro-renewable technologies

Q (1) : In your opinion which micro technologies from your perspective are most suitable for new settlement with regard to environmental and landscape criteria? Please, write down your preferences and why you selected them. *(Wind Turbines, Solar* Photovoltaics*, Solar Thermal Collectors, Biomass Power Plants, Geothermal Vertical Loops, Geothermal Horizontal Loops)*.

1. ………

2. ………

3. ………

……

………

………

………

………..

Q(2): Which micro renewable combinations do you prefer and why? *(For example Solar panels for electricity production and Geothermal vertical loops for heat production)*

Electricity production: Solar Photovoltaics **(SP)**, Wind Turbines **(WT)**, Biomass power plants **(B).**
Heat production: Solar Thermal Collector **(STC)**, Geothermal Vertical Loops **(GVL)**, Geothermal Horizontal Loops **(GHL)**, Biomass power plants **(B)**.

Electricity production	**Heat production**
1.	**1.**
2.	**2.**
3.	**3.**

………

………

……

……

……

Q (3): Was having the 3D visualization examples of an energy efficient residential development (i.e. Annex 1) been helpful in completing the questionnaire?

☐ very helpful
☐ some help
☐ little help
☐ no real benefit
☐ unhelpful

Why was the visualization helpful or unhelpful?

……

……

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………………………………………………………………………………………………

Any suggestions, comments or remarks

……

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……

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THANK YOU FOR YOUR COLLABORATION!

ANNEX 2: Python code for biomass energy potential using Monte Carlo integration

```
#!/usr/bin/python
##
try:
    from osgeo import gdal, osr
    from osgeo.gdalconst import *
    import numpy as Numeric
    from math import *
    from random import *
except ImportError:
    import gdal
    from gdalconst import *
    import Numeric
    from math import *
    from random import *


import sys, os


def createTiff(fname, xsize, ysize, nband, type):
    driver = gdal.GetDriverByName("GTiff")
    dst = driver.Create(fname, xsize, ysize, nband, type)
    return dst

def writeTiff(dst, band,  data):
    outband = dst.GetRasterBand(band)
    outband.WriteArray(data)

def createJpeg(tmpname, jpgname):
    jpg_driver = gdal.GetDriverByName("JPEG")
    src = gdal.Open(tmpname)
    jpg_driver.CreateCopy(jpgname, src, 0)

def createPng(tmpname, pngname):
    png_driver = gdal.GetDriverByName("PNG")
    src = gdal.Open(tmpname)
    png_driver.CreateCopy(pngname, src, 0)

def createAscii(tmpname, asciiname):
    jpg_driver = gdal.GetDriverByName("AAIGrid")
    src = gdal.Open(tmpname)
    jpg_driver.CreateCopy(asciiname, src, 0 )


def Ellipse(cx,cy,dx,dy,maxx,maxy):
    start = 1
    while(start):
        rx = 2.*random() - 1.
        ry = 2.*random() - 1.
        x1 = cx + dx*rx
        y1 = cy + dy*ry
        d2 = (x1 - cx)*(x1 - cx) + (y1 - cy)*(y1 - cy)
        okx = 0
```

```
        oky = 0
        okd = 0
        if(x1 > 0 and x1 < maxx):
            okx = 1
        if(y1 > 0 and y1 < maxy):
            oky = 1
        if(d2 <= dx*dx + dy*dy):
            okd = 1
        if(okx and oky and okd):
            break
    point = (x1,y1)
    return point


def Biomassen(data):
    nx = data.shape[0]
    ny = data.shape[1]
    maxd = sqrt(nx*nx + ny*ny)/8.
    vals = Numeric.zeros([nx,ny])
    minx = int(nx/8.)
    miny = int(ny/8.)
    centerx = 0
    centery = 0
    passox = 5
    passoy = 5
    Nmontec = 5000
    sum = 0
    for x in range(minx,nx-minx,passox):
        #if(x%50 == 0):
        print x
        for y in range(miny,ny-miny,passoy):
            for j in range(1,Nmontec):
                (x1,y1) = Ellipse(x,y,minx,miny,nx,ny)
                if(data[x,y] != 1):
                    if(data[x1,y1] == 1):
                        dist = sqrt((x - x1)*(x - x1) + (y - y1)*(y -y1))
                        vals[x,y] += (maxd - dist)/maxd
                    else:
                        vals[x,y] += 0

                     #vals[x,y] += int(dist)
            for xx in range(x,x+passox):
                for yy in range(y,y+passoy):
                    if(xx < nx - minx and yy < ny - miny):
                        vals[xx,yy] = vals[x,y]
    fin = vals
    return fin

def processData(fname,foutname,  ox, oy, dx, dy, nb, type, min, max, ncol):
    print fname,foutname,  ox, oy, dx, dy, nb, type
    indataset = gdal.Open(fname, GA_ReadOnly )
    dst = createTiff(foutname, dx, dy, nb, type)
    for iBand in range(1, nb + 1):
        inband = indataset.GetRasterBand(iBand)
        data = inband.ReadAsArray(ox, oy, dx, dy)
        da = Biomassen(data)
        writeTiff(dst, iBand, da)

def getInfo(fname):
    indataset = gdal.Open(fname, GA_ReadOnly )
```

```
    band = indataset.GetRasterBand(1)
    vg =[]
    (min,max) = band.ComputeRasterMinMax(1)
    vg.append(min)
    vg.append(max)
    return vg


fout = "mappa.jpg"
fpng = "mappa.png"
fascii = "mappa.asc"
ftmp = "mappa.tif"

fin = "/tmp/aval.tif"


origx = 0
origy = 0
deltax = 1570
deltay = 1280
nbands = 1


extr = getInfo(fin)
min = extr[0]
max = extr[1]

ncolors = 255

print min,  max
#sys.exit()

type = GDT_Float32
processData(fin, ftmp, origx, origy, deltax, deltay, nbands, type, min,
max, ncolors)
#createJpeg(ftmp, fout)
createAscii(ftmp, fascii)
#createPng(ftmp, fpng)
```

ANNEX 3: Example of weights calculation and consistency test calculation (CR<0.1)

$n := 5$

$RI(n) := 1.12$

$$A := \begin{pmatrix} 1 & 4 & 4 & 6 & 6 \\ \frac{1}{4} & 1 & 2 & 2 & 4 \\ \frac{1}{4} & \frac{1}{2} & 1 & 6 & 2 \\ \frac{1}{6} & \frac{1}{2} & \frac{1}{6} & 1 & 1 \\ \frac{1}{6} & \frac{1}{4} & \frac{1}{2} & 1 & 1 \end{pmatrix}$$

$$\text{eigenvals}(A) = \begin{pmatrix} 5.354 \\ -0.14 + 1.276i \\ -0.14 - 1.276i \\ -0.037 + 0.473i \\ -0.037 - 0.473i \end{pmatrix}$$

$$\text{eigenvec}(A, 5.354) = \begin{pmatrix} -0.882 \\ -0.337 \\ -0.291 \\ -0.109 \\ -0.112 \end{pmatrix}$$

$C := \text{eigenvec}(A, 5.354)$

$$S := \sum_{i=0}^{n-1} C_i$$

$S = -1.731$

$$B := \frac{C}{S}$$

$$B = \begin{pmatrix} 0.509 \\ 0.195 \\ 0.168 \\ 0.063 \\ 0.064 \end{pmatrix}$$

$$\lambda max := 5.354$$

$$CI := \frac{(\lambda max - n)}{n - 1}$$

$$CI = 0.089$$

$$CR := \frac{CI}{RI(n)}$$

$$CR = 0.079$$