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Renewables in residential development

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

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Abstract

In recent years there has been an increasing interest in using alternative and renewable energy sources to heat or power homes. Micro-renewable generation involves energy production on a small scale (e.g. via wind, solar, biomass and geothermal sources) to supply low-consumption buildings. Such technology can help ensure security of supply and promote sustainable development, but knowledge is still lacking about how to best integrate it into housing developments in order to optimize energy efficiency, environmental concerns and other criteria for new settlements. 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 environmental concerns and the preferences of (urban, spatial) planners as to settlement locations.

Spatial variations in energy potential were evaluated by adapting existing methods in the literature and expert interviews, as well as 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 a GIS via a weighted linear combination method to generate spatially explicit outputs for the eastern metropolitan area of Cagliari, Sardinia. One map represented suitable areas for new settlements and a second one 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 about sustainable energy efficient housing development and indicate areas with conflicting demands, as well as 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 evaluating energy potentials, to track changes and to reach out the best solution. According to expert preferences there were identified many alternatives for future housing development, which can be integrated at the beginning of the planning process of land use plans or development plans.

Abstract

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 Energieffizienzgesichtpunkten in Siedlungsplanungsprozesses von Entwicklungs- oder Flächennutzungsplänen integriert werden können.

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1. Background

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

A sustainable future of cities accordingly depends significantly on planning of the urban growth in a sustainable way. In this context energy efficiency of new housing developments in combination with a minimization of environmental impacts is a prime objective. In Europe this general goal is supported by the EU's energy policy target of achieving 20% reduction in carbon emissions, 20% improvement in energy efficiency and of covering 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 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 not only put in place legislation to promote renewable energies but also is faced with the challenge of integrating growing amounts of intermittent power sources like solar and wind into the electricity grid. Furthermore, to achieve the goals of the EU directive, 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 characterized by intermittency, therefore it is the imperative that a mix of sources be selected and used along with some energy storage mechanism to best use the renewable energy resource and ensure a continuity of energy supply (MACLEOD: 2007, 1804). Therefore the installation and utilization at a large scale of renewables presupposes relevant changes of all sectors of energy use, legislative and organizational modifications and in most cases significant investments.

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). The UK Government through the means of the Energy Act 2004 defines micro-generation as generation of a capacity of less than 50 kW (the peak demand for a house in the winter is around 20kW). The National Italian Law N. 239/2004 art.85 defines it as a production and energy transportation system based on the integration into electricity grid of micro generators with total power of less than 1 MW using renewable power sources. This technology has many advantages: high energetic efficiency, reliability, safety and blackout prevention and mitigation, low environmental impact, low noise level (BEITH ET AL. 2004, 3). The electric line is more reliable, with less problems for the consumer (voltage is more constant); moreover the micro generation helps in furnishing electricity in remote areas (country sides and mountains). Building micro generators near the consumer helps in containing the costs of line capacity and transportation(ibid.).

Smart grids, called intelligent grids, will be the key at local distribution level for reducing peaks in electricity demand, in order to increase its 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). That is expected to transform today's power distribution systems from centralized energy production and one-way transmission to flexible, interactive, bidirectional, efficient distribute electricity systems (NIST 2010, www). The household, originally conceived as passive in receiving energy now has to become active in producing energy itself and the electricity production should be varied in reacting to the 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.

2. State of science

2.1 Sustainable development

In 1987 in the famous 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,* which is considered as one of the basic dimensions of the sustainability definition. After that, the UN World Climate Conference in 1995, Habitat II in 1996 and the Kyoto protocol in 1997 emphasized the use of new concept and technologies for a sustainable development. According to the OECD, a sustainable development should be aimed to the effectiveness of land use planning and regulations to promote the use of renewable energy resources (OECD, 1995). During the preparatory meetings for the Global Conference on the Urban Future (Berlin, July 2000) a 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)."

Sustainable cities, or eco-cities have to be planned with minimizing energy, water, food and pollution. The city is the result of three main forces, the social, environmental and economic forces, which are interlinked and intersected (CAMAGNI 1999). Accordingly, housing development needs new concepts for housing with as little environmental impact as possible and the integration of several complex interrelated social, economic, political, spatial, institutional and physical factors (DROEGE 2008; RANDALL 2008). Urban sustainability from a strategic planning perspective focus on the prospects for using changes to transport and urban form to reduce energy consumption. Especially, transport management, building design, land use planning and energy efficiency are the main issues discussed toward an urban sustainable development. However, the current city planning practice does not include an effective land-use energy evaluation in the urban plans (DUVARCI & KUTLUCA 2008). Energy concepts are not well integrated into the planning process in detail with form, design and planning (OWENS 1986; SADOWNIK & JACKARD 2001; MEANS 2004). There are strong relationships between energy and planning components which are land-use, built form, transportation, urban form, and infrastructure systems. With the appropriate planning and design tools cost and pollution can be reduced. In general, linear urban forms and high density had relevant contributions in optimizing efficient energy use (MCGEOUGH ET AL. 2004; LANTZBERG 2005). Low density urban sprawl generates a greater need to travel than a more compact pattern of mixed land use where the physical separation of activities is small, as well as infrastructure costs (OWENS 1989; OECD 1995). Another important issue is the design, both urban and building scales for energy efficiency and energy consumptions (JEBSON 1981; FANCHIOTTI 1993; BHATT ET AL. 2010). At urban scale energy efficiency has been maximized with urban form and transport systems (BEAUMONT & KEYS 1982; JONES

ET AL. 2001) . Some applied models related to urban form, transportation and urban heating systems have been developed (ORTUZAR & WILLUMSEN 1994; COOPER ET AL. 2001), with the hypothetical proposals of optimum urban form as well (BAKER & STEEMERS 2000). Planners need to explore the impacts of energy-saving tools on land-use, and the impacts of land use changes on the energy-saving (CF. BHATT & GINSBERG 2009). However, environmental impacts caused by transportation energy systems have been extensively investigated (Anderson 1996; KENWORTHY & LAUBE 1999; HOLTZCLAW 2002).

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 encompasses energy-integrated land use planning. European cities such as Goteborg and Stockholm (Sweden), Freiburg (Germany), Aahrus (Denmark), Turin (Italy), Sutton (London, UK), Rennes (France) are models of an energy efficient housing development (cf. DUVARCI & KUTLUCA 2008). The focus is strongly on energy-efficient design and technology, quality of urban planning strategies in order to increase the degree of sustainable development (ROTMANS ET AL. 2000). In this context two European projects are worth mentioning: 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 also they take into account social and economical aspects: both models achieve greater sustainability combining local public policy, planning, design and technology (cf. ENERGYCITIES 2010). From this point of view, energy saving measures such as better insulation or solar exposure represent only few requirements for a sustainable development based not only on energy efficiency concepts, whereby energy efficiency criteria are one of the most important part of both projects. However, a 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 scales, an integrated systems approach seems to make sense to analyze the complexity of city planning (cf. ROTMANS ET AL. 2000). For instance, the open citizens' participation during the planning process can raise the acceptance of micro renewable technologies and improve their use. Taking into account that the planning of a sustainable development is a complex issue, made up of several and quite often different aspects, in the following description and analysis of both projects the focus is 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. According to this, other aspects, like transport, water, waste, local materials, social perception and participation are only mentioned. It is clear that economical, environmental and social factors should be considered simultaneously and in a close relationship, but this is not investigated in dept in the present work. However, this can be a next step for further research.

Beddington Zero Energy Development (BedZED)

BedZED is the UK's largest mixed use sustainable project, which 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 show that in large-scale construction a high level of sustainability could be practical and cost-effective. The project aimed to reduce its ecological impact both in construction and operation and to help residents to live within their fair share of the local resources (ibid.). Building materials were sourced locally, and heat and power for the residents has been provided by renewable energy technologies.

The project has comprised 82 homes and 2,500 m^2 of commercial or live/work space: 50% housing were for sale, 25% were key worker shared ownership and 25% were 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 works on the wood waste from a close 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 related to the planning for density, combined with optimal solar exposure as well as daylight, fresh air, and private open space access. According to the architect *it is 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 also through a large installation on the south-facing portion of the roofs. 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 about the monitoring of the project showed that the electricity consumption of the average BedZED citizen was 45% less than that of the other residents of Sutton County. The heat consumption was 81% lower and the use of water was reduced 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 combined heat and power plant (CHP) started gradually to drop from 80% of BedZED's energy produced from renewable sources in 2003 to 11% in 2006. Even without the use of these systems, and with the goal of 'zero (fossil) energy' not being achieved, BedZED has considerably reduced its carbon footprint (IBID.).

Some countries, most remarkable Germany, following a mandated solar energy pricing policy, which aims at starting a new generation of buildings and architectural responses. The City of Freiburg (Germany) is recognized as 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 taken over 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 has been in charge for its planning and development. The principle "Learning while Planning", adopted by the city allowed flexibility in reacting to new developments (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 considering several aspects in a ecological (public transport, co-generation plant, heating system, renewable energy, green areas); economical (balance of working and living areas, district shopping centre); social and cultural way (neighborhood centre for social interaction, cultural events) (IBID.). The project's structure integrated legal, political, social and economical participants from grassroot-level up to the city administration. Right from the beginning all issues (mobility, energy, housing, social aspects etc.) were discussed in working groups which were open to residents (STADTTEIL VAUBAN, FREIBURG, 2010). During the planning process the City opened an extended citizen participation process and supported this process also financially. This allowed an extended citizen participation that went far beyond the legal requirements and allowed citizens to participate in the planning process. From the very beginning, the citizen's association "Forum Vauban e.V." did not want to restrict itself to merely organizing but also developed own proposals for the planning and building of the district (IBID.). Therefore, the project was created and implemented not only along with the City of Freiburg but also with several other partners. The feature of cooperative local planning was an outstanding characteristic of the Vauban. In the fields of energy, traffic, mobility, building and participation, social interaction, public spaces new concepts were successfully put into practice (FREIBURG CITY 2010, www). 2007 the city council adopted a consistent procedure – developed by the planning and environmental department - integrating energy aspects for all new development plans (IBID.) Each new development plan includes:

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

Energy concepts were integrated through variant verification central/decentralized, CHP (combined heat/power), early involvement of renewable energies. More in details the project about energy efficiency included:

- ✓ 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" (they produce more energy than they need)
- ✓ planning a district heating grid; co-generation plant (wood chips: 80% and gas: 20%)
- ✓ massive use of solar energy with 2,500 m^2 of photovoltaic panels and 500 m^2 of solar thermal collectors

The implementation was based on agreements on urban development between the city and private owners. In particular, 65% of the electricity needed in Vauban is produced on-site through CHP and photovoltaics. Low-energy housing costs around 2% more to build than traditional housing, yet energy consumption falls by up to 80% compared to existing building stock and CO2 emissions were reduced by 30% (STADTTEIL VAUBAN, FREIBURG, 2010). In Freiburg, the principles of energy savings and solar optimization were combined early in the planning phase of housing development, for example, by defining the orientation and position of buildings or by obligatory low-energy construction requirements (cf. PASSIVEHOUSE »WOHNEN & ARBEITEN«, 2010).

The suitability of micro-renewable is dependent on several factors, including: availability of energy potential, building design, orientation and location. Environment-oriented eco-districts integrate sustainable design, optimize building orientation, thoughtfully plan transportation by expanding an existing or developing new residential areas. In both examples renewable technologies were integrated at the project's scale considering the renewable energy potentials according to local characteristics (e.g. terrain and exposure) of the development areas. For instance, in both models the new housing development was located on dismissed areas near the city (Bed-Zed) or on military areas (Vauban). The best location is not selected between more alternatives considering environmental criteria and micro renewable potentials. Renewable energy has not been established adequately in current planning practice, especially in development and land use plans (cf. DUVARCI & KUTLUCA 2008). Alternative planning approaches to integrate energy efficiency in development and/or land use plans based on energy efficiency are not far developed yet. In Freiburg energy concepts, which primarily take into account solar and biomass energy, have been integrated in new development plans. In particular, in Vauban energy efficiency has been increased through the introduction of passive and/or active houses, which are example of buildings with low energy consumption (cf. PASSIVHOUSE INSTITUT 2010, www). Actually, energy plans provide energy potentials by identifying the best locations for optimizing energy sources but they not take into account the integration of micro renewable technologies in new settlement developments (cf. BEYER ET. AL. 1997; WILLSON & GALLANT 2000). Considerations of energy efficiency should be integrated at the start of the land use planning process in order to guide future development to the sites with the best potential for using renewable micro generation. These potentials can be developed in a sustainable way by using multicriteria evaluation methods in a GIS to help optimize new settlements in terms of multi-functionality. In this context, up to now the research is still lacking about 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. Accordingly, there are a lot of open questions on 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 and how to optimize the settlements in terms of multi-functionality.

2.3 State of methodology development

Many urban planners propose several urban designs from the point of view of energy consumption without considering energy potentials (LYLE, 1994; WILLIAMS & JENKS, 2000). By the contrary, much research has been done on the technical aspects of micro generation (BROOKES 2004; ROSEN ET AL. 2005; LINDEN ET AL. 2006). However, the renewable energy potential at regional and sub-regional scale for micro-renewables is not considered or 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, inappropriate locations of new houses cannot completely exploit the renewable energy potentials. Therefore, 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 could be obtained in different manners: using data from solar radiometers of meteorological stations or making direct calculation from astronomical and geographical parameters (sun declination, duration of the day and latitude). In Europe the solar irradiation is derived from 566 meteorological stations and solar data algorithms to calculate derived parameters, mapping in digital form are collected into a database in the European Solar Radiation Atlas (ESRA) (HELIOCLIM 2010, WWW). To produce spatial databases from these measurements various techniques can be used like interpolation techniques or data 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 they give an advantage to cover large territories (SÚRI AND HOFIERKA, 2004). All these techniques could be used to produce spatial databases in the geographical information systems (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, using the *r.sun* model and interpolation techniques with 1 km resolution considering surface inclination, terrain aspect and shadowing effects, but they are 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 required to estimate the energy potential for housing development at local or sub-regional scale, more accurate inputs data 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 data of meteorological stations. The wind speed were modeled by using statistical models taking into account land parameters like roughness, elevation, topography and ground surface cover. In Europe the wind speed distribution was obtained from 200 stations. These data and maps are contained in the European Wind Atlas, 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 the ground level on shore and off shore (EUROPEAN WIND ATLAS 2010, www). However, every country has 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 geographical location, the relief and the land use (roughness) using a non-linear regression. Furthermore, in Italy, the Italian Wind Atlas ("Atlante eolico italiano") was developed in 2002 by CESI RICERCA in co-operation with the Department of Physics of 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 metereological stations. The Atlas contains series of 27 maps (1:750.000) of annual average wind speeds (m/s) at 25, 50 and 70 m height above ground level, 27 maps of energy production (MWh/MW) of a hypothetical wind turbine of 50 m height and synthesis maps (1:6.000.000) (CASALE ET AL.2010: 17). The model was first applied to 24 different geographical areas, each 200x200 km in size. The wind data were referred to a grid of about 1x1 km in latitude and longitude. The accurateness of wind energy potential maps depend strongly on wind data availability of each country. In comparison to the solar energy potential, for wind is not possible to use other data, but only to derived them for a smaller scale considering wind speeds and relief.

State of methodologies for assessing the geothermal energy potential

Geothermal energy could be divided into two categories: high-entalpy geothermal energy for big power plants and low-entalpy 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 almost at any place from the soil, rocks and from groundwater (ibid.). The European Geothermal Energy Council (EGEC) has developed a map showing main basins and high-entalpy geothermal areas (EGEC 2010, www). The low-entalpy geothermal energy needs to be investigated at a bigger scale. Several regions in each country have developed studies and maps for identifying the energy potential for borehole heat exchangers (vertical loops) and horizontal ground heat exchangers (horizontal loops). For instance, the energy potential for horizontal loops (1,2 - 1,5 m installation depth) in Lower Saxony, Germany, is shown by the map for “potential site's suitability for geothermal heat collectors map" with 1:50.000 scale (LBEG). Not all region have developed geothermal energy potential maps, therefore it is required to take into account the geological map and to consult experts to estimate the ground composition and the rocks stratification.

State of methodologies for assessing the 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 (EEA). The EEA has developed a potential map showing the “Suitability for residue extraction according to environmental criteria” (EEA 2006). The biomass potential consists of forest residues. The bioenergy potential has been mostly determined by the market demand for wood and traditional wood use was restricted to current prices structures. The European Forest Information Scenario (EFISCEN) model, has taken in input national forest inventory 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 were expressed in tOE per km^2 of land area and were determined by overlaying the suitability map and the forest map (EEA 2006). EFISCEN simulates only forest areas that were available for wood supply. Unproductive forests as well as nature conservation areas were excluded. The limit of the existing methodologies in estimating the biomass energy potential is that the distance from the forested areas to the potential new settlement is not far considered.

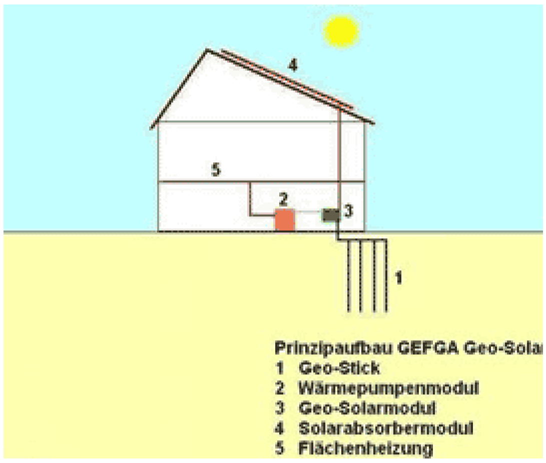
2.4 Micro renewable energy efficiency mix combinations and potentials

The state of the art is sufficiently advanced in the field of energy efficiency (Brookes, 2004; Rosen et al., 2005; Linden et al., 2006), which may be increased by combining different energy sources. Accordingly, an important element of a sustainable settlement should be structures which tackle the challenge of increasing the share of renewable energy sources in the energy mix (MACLEOD: 2007, 1804). Up to now, there are a lot of open questions concerning the multifunctional combination of different renewable energy sources and other aspects of sustainable settlement development in the most efficient way. However, 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 can be a restriction to secure supplies but can be minimized by demand variability, especially where this correlates with times of high energy output by renewables, better predictability of their generation output and the complementarities of different power sources (IEA, 2007). Regional variations capacity factors and variability of the availability implicates that security of renewable energy supply is site specific (ibid.). There are three categories of energy sources with respect to their relationship with weather/climate variability (von Bremen 2010):

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

There are a lot of advantages from the energy combination, because the energy mixes can cover 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). Accordingly, some solar thermal systems make use of heat storage to produce heat when the sun is not shining. Wind power generation is much stronger in winter than in summer; the opposite is for solar power generation (Heide et al. 2010). The output of wind power is driven by environmental conditions outside the control of the generators or the system operators. Energy supply from wind turbines is stochastic in nature and the power is proportional to the third power of wind speed (HOLTTINEN 2005). The wind output varies not only seasonally between summer and winter but the variations are also present on shorter time scales, namely on hourly basis [2] T. Hamacher, T. Haase, H. Weber and J. Düweke, Integration of large scale wind power into the grid, *Power-Gen Europe 2004* (2004).(HAMACHER ET AL 2004). Wind-generated power is a variable resource, and the amount of electricity produced is dependent on wind speeds, air density, and turbine characteristics (among other factors). If wind speed is too low (less than about 2.5 m/s) then the wind turbines will not be able to make electricity (SCHNELLER 2005). Up to now, 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). While photovoltaic panels and solar thermal collectors provide electricity and heat, usually on the roof of the houses; micro wind turbines, also installed on the roof or in garden, produce electricity. Depending on their location, homes with low energy requirements, the combination of these two systems may be enough to provide their electricity needs, as solar energy can be stored, while wind energy can immediately supply energy requirements as long as the wind turbines are able to collect wind kinetic energy (MOURA & DE ALMEIDA 2010).

In addition, 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 moderate temperatures in the shallow ground to increase efficiency and minimize operational costs. Being a site dependent issue, geothermal energy includes quite special relations and contradictions to land-use planning process than other renewable energy types (DUVARCI & KUTLUCA 2008). It may be combined with solar heating to form a geosolar system with even greater efficiency (GEO-SOLAR SYSTEMS 2010, WWW). As a result of solar radiation measured, the excess energy can be stored in the underground and thus saving electrical energy to power the boreholes (ROSINSKI 2007). Also effective is the combination of solar and biomass energy. During the summer months biomass heating or co-generation systems have, only a limited time of application, because there are no needs for space, but only for water heating. Therefore, it is economic and ecologically efficient, that the hot water is provided in summer by a solar system. This covers completely the usual hot water demand in the summer months and stores *surplus energy* available 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 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, such as the International Human Dimensions Programme on Global Environmental Change (IHDP) within the framework of "Cities and Industrial Transformation" (ROCKWELL 1999; ROTMANS 1998), 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*. Integrated Assessment has mainly been applied to environmental problems, but it is broadly recognized that it could address complex problems such as city planning. From this point of view, the geographical distribution of the micro renewable energy potentials can be integrated at the beginning of the planning process of land use and/or development plans in order to guide future development to the sites with the best potential using micro renewable generation. Thus, the energy potential estimation allow regional and urban planners to plan the most efficient energy mix for new housing areas in a given region, optimizing the new settlements in terms of multi-functionality. On the other hand, a sustainable approach can 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 uses 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, a geographic information system (GIS) is widely recognized as useful tool for environmental planners in determining the most/least suitable locations for development or resources allocation.

Methods for assessing housing site suitability using GIS

The 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 used in several situations including 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 the 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 land suitability are to find 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 geocomputation) methods (cf. COLLINS ET AL. 2001). The **computed-assisted overly techniques** were developed to cover 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.

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

However, recent developments in spatial analysis show that **AI (Artificial Intelligence)** offers new opportunities to the land-use suitability analysis and planning (OPENSHAW & ABRAHART 2000). Broadly speaking, AI is based on modern computational techniques that can help 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).

Broadly speaking, the classical overlay mapping and modeling approaches are the most commonly used methods for land suitability analysis in GIS environment. The major limitation of these approaches is that they are still lacking in integrating decision-makers preferences into the GIS-based procedures. This limitation can be solved by combining GIS and MCDM methods. The main problem associated to the MCDM is 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 have been realized to integrate decision making in complex problems such as site selection, land suitability analisys, 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 geographical or spatial decision problems (MALCZEWSKI 1999). Spatial problems can be solved using multi-criteria decision making (MCDM) based on geographical information system (GIS). GIS techniques and procedures present unique capabilities for automating, managing, and analyzing a variety of spatial data to provide support for spatial decisions (GRIMSHAW 1994). Therefore GIS should be considered as a process rather than as purely software or hardware. Multi-criteria decision-making procedures define a relationship between "input data" and "output data". To solve spatial decision 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 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 comparing scenarios (CARVER 1991). Land suitability analysis is the process of determining whether the land resource is suitable for some specific uses and to determine the suitability level (STEINER ET AL. 2000). Furthermore, spatial multicriteria analysis needs information on criterion values and the geographical locations in addition to the decision makers' preferences according to a set of evaluation criteria. This means that analysis results depend not only on the geographical distribution of attributes, but also on the stakeholders' value judgments involved in the decision making process (see Figure 5). Therefore, two components are significant for spatial multicriteria 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 makers' preferences (CARVER, 1991; JANKOWSKI, 1995).

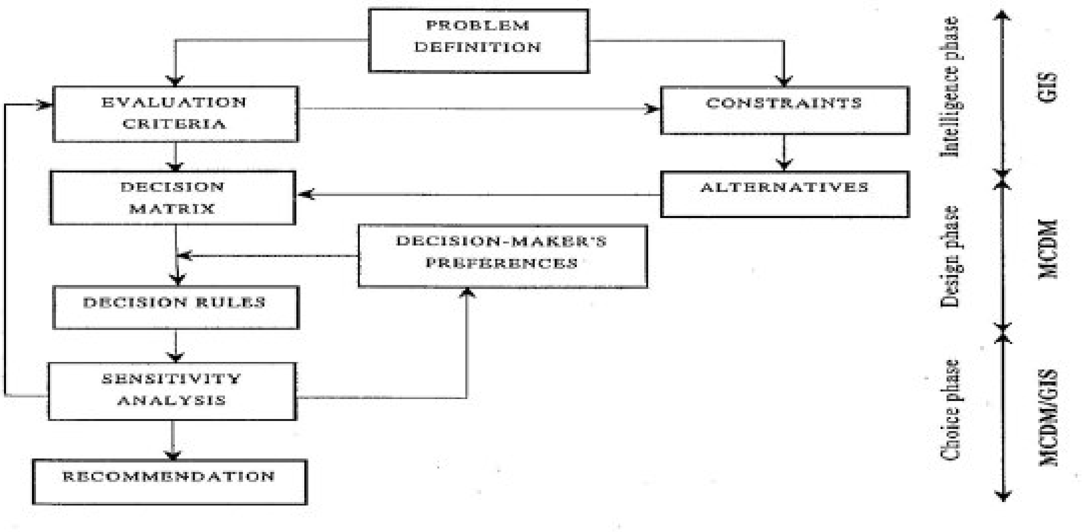


Figure 5: Decision flowchart for spatial multicriteria analysis (Malczewski, 1999).

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 using 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 done through digitizing, geo-referencing and entering data that describes their characteristics (HYWOOD ET AL. 2006).

GIS allows to work with layers of spatial data and commands of operation processes to achieve of suitability locations. Carver (1991) states that though GIS provide the decision maker with a powerful set of tools for the manipulation and analysis of spatial information. On one hand, GIS only allow the decision maker to identify a list of sites meeting a predefined set of criteria (JIANG & EASTMAN 2000). On the other hand, GIS does not allow the decision maker 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 multicriteria evaluation methods have been implemented in the GIS environment including weighted linear combination (WLC) and its variants (JANSSEN AND RIETVELD 1990; EASTMAN 1997), analytical hierarchy process (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 the decision-makers 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 set, (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 which is 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 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 prioritizing 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. The analytical hierarchy process (AHP) can be utilized in two different ways within the GIS environment: first, it can be employed to calculate the weights associated with the criteria , and second, the AHP principle can be used to aggregate the priority for all hierarchical levels including the level representing alternatives (SAATY 1977). Such multicriteria decision problems are typical for housing sites 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.

MCDM problems involve criteria of varying importance to decision makers and 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 the decision maker's 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 the decision makers preferences;

- *rating methods,* which require the estimation of weights on the basis of predetermined scale;

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

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

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 developments by first estimating the geographical 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 developments as well as optimizing the mix of micro renewables should be facilitated by such a methodology. The integration of renewable energy efficiency from solar, aeolic, biomass and geothermal resources into new housing development is directed to regional land use plans and/or local development plans.

The main research questions investigated are:

- How to calculate the geographic distribution of the energy potentials? 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 to include multiple further criteria into housing development decision?
- Which environmental and landscape criteria are considered relevant for the assessment new housing development with micro renewable technologies?

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

4. Methodology and data

4.1 General methodological approach

The newly developed methodological approach is based on the one hand on existing methods for energy potential assessment, which were pre-tested in the region of Hannover (by master students and the author in cooperation with the State Office for Mining, Energy and Geology (LBEG) and under the supervision of Prof. Christina von Haaren and Prof. Michael Rode, Leibniz Universität Hannover, Germany (BREDEMEIER ET AL. 2009)) as well as in the Cagliari test region. Also the methods were adapted to local/regional scale planning. This resulted in the assessment of the theoretical potential, which describes the theoretical 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).

On the other hand expert preferences were used for weighting environmental assessment criteria. This resulted in modeling a 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 no clear cut standards about the suitability of micro generation in residential areas (in contrast e.g. to emission standards) pre-define decision priorities about suitable locations; thus using expert opinions were a simple way of priority setting in complex decisions;
- furthermore it supports the planning process as general preferences of decision makers can be automatically translated into spatial scenarios;
- in principle the method can be used for modeling the consequences of different preferences and allows for including local or regional stakeholder opinions and interests.

To identify the optimal sites for energy efficient housing development by a GIS based multicriteria analysis at regional scale the steps below were followed:

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

2a) Identifying favorite sites for new housing development chosen by students, academic planners, regional environmental planners and public authorities from Italy, Germany and UK.

2b) Determining the favorite sites for new housing developments with renewable micro technologies also chosen by the experts

3. Processing the data from Steps 2a and 2b

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

Research Steps	**Research questions**	**Methods**
Which methodologies have to be applied or developed to estimate the theoretical energy potentials for each micro renewable energy (solar, wind, wood biomass and geothermal energy) to obtain raster maps (geographical distribution of energy potentials)?		
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? Are the data accurate for estimating the energy potential the regional scale? • Which software, compatible with ARC GIS, are available and suitable in terms of scientific validity?	State of the art research methods Analysis of the main methods used for the estimation of the micro energy potentials Case studies analysis
Which method has to be applied to create raster maps for identifying the favorites sites for new housing development chosen by students and academic planners and regional environmental planners and public authorities from Italy, Germany and UK? Which method has to be applied to select the favorites sites for new housing development using renewable micro technologies also chosen by the experts?		
Expert survey (questionnaire)	• Which criteria are to be selected for a sustainable urban development? • Which criteria are to be selected in order to consider environmental and landscape impact of micro technologies? • Which experts are to be addressed with the questionnaire? • What are the differences between the expert preferences? What are the differences between expert preferences and energy potentials? What are the differences between energy potentials and micro-renewables 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.

How raster maps have to be combined to obtain the final raster maps showing the optimal sites for new energy efficient residential areas for Italy, Germany and UK? Which are the best locations for new energy efficient settlements? How can different micro-renewables be combined? Which consequences can this method implicate for future housing development based on this new approach? What will be the next step of the research?		
Results maps showing 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 area have to be excluded? According to the experts opinion should take place any residential development on environmentally valuable and vulnerable areas? • Which micro-renewables can be combined? Which are antagonistic? Which combinations do experts prefer and why? • Which requirements about data availability, validity, 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

4.2 Adaptation of an 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 (solar thermal collectors) and electricity production (photovoltaic panels). The solar radiation on the Earth's surface depends on the latitude with the highest value in tropics and the lowest around the poles (HOFIERKA & CEBECAUER 2008). In fact it is influenced by astronomic factors such as Earth's geometry, revolution and rotation (declination, latitude, solar hour angle). On the other hand, factors which contribute to the atmospheric attenuation (scattering, absorption) are gases (air molecules, ozone, CO_2 and O_2), solid and liquid particles (aerosols, including non-condensed water) and clouds (condensed water) (JRC 2010a, www). The radiation to the Earth's surface is also affected by its terrain topography, namely slope inclination and aspect, as well as shadowing effects of neighbouring terrain features. The elevation above sea level determines the attenuation of radiation by the thickness of the atmosphere. The geographical factors, spatial and temporal distribution of renewable energy resources require maps-based assessment of 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 period including 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 web page (ibid.). The *r.sun* model, requires as input data the digital elevation model (DEM) for the estimation of global solar radiation (beam, diffuse and reflected) for the clear sky and overcast atmospheric conditions (ŠURI ET AL. 2006). A very important factor to produce reliable maps of solar irradiation was the estimation of the cloudiness of the sky, because the total amount of clouds strongly affects the ground irradiation. For this reason the data are validated using *pvgis* data. The output was a raster map of global irradiation annual average for 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 the clear sky and overcast atmospheric conditions (SÚRI & HOFIERKA 2004). While the calculation of the beam component is quite straightforward, the main difference between the various models available in the literature is in treatment of the diffuse component (PEREZ ET AL. 1987). This component depends on climate and regional terrain conditions and it is often the largest source of estimation error. The cloud effect is not directly taken into account but could be considered averaging cloudiness data from meteorological station datasets.

The clear-sky solar radiation model applied in the *r.sun* is based on equations published in the European Solar Radiation Atlas (ESRA) (SCHARMER AND GREIF 2000; PAGE ET AL. 2001; RIGOLLIER 2001). The algorithm used to calculate the solar irradiation is implemented in the Open Source GIS software GRASS, where the beam irradiance normal to the solar beam *B0c* [W·m-2] is attenuated by cloudiness atmosphere and calculated in the model as in the formula (1) (JRC 2010a, WWW):

$B_0c = G_0 \exp\{-0.8662 \text{ TLK } m \text{ dR}(m)\}$ (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"; dR(m) is the "Rayleigh optical thickness at air mass m"

In contrast to other models, *r.sun* 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 then it was used easily for long-term calculations at different map scales – from continental to local (SÚRI & HOFIERKA 2004).

Input parameters

The r.sun model operates in two modes, that can be used separately or combined to furnish estimates for any request time steps or intervals. In *mode 1* the model calculate for the instant time [sec] raster maps of chosen components (beam, diffuse and reflected) of solar irradiance [W.m^{-2}] and solar incident angle [degrees]. In *mode 2*, the raster maps of daily sum of solar irradiation [Wh.m^{-2}.day^{-1}] are computed as integration of irradiance values that are calculated within a set day. In this work is used the *mode* 2 because we need to calculate raster maps representing one annual average of daily sums of global irradiation for horizontal surfaces. To compute the irradiation raster maps *beam_rad*, *diff_rad*, *refl_rad, r.sun model* requires only a few mandatory input parameters – digital terrain model (elevation, slope, aspect – *elevin*, *slopein*, *aspin*), day number *day* (for mode 2), and additionally a local solar time *time* (for mode 1). The other input parameters are either internally computed (solar declination) or the values can be set to fit the specific user needs: Linke atmospheric turbidity, ground albedo, beam and diffuse components of clear-sky index, time step used for calculation of all-day irradiation (SÚRI & HOFIERKA 2004). Solar declination is computed internally and day number unless an explicit value of *declin* is used. In the case that users data are localized in GRASS location with defined projection, *r.sun* uses internal GRASS function to get geographical latitude for every raster cell (see Grass 6.3 manual page). The Linke turbidity factor and ground albedo can be set as a 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 an absolutely clear atmosphere is *lin*=1.0 (see Grass 6.3 manual page). To avoid the overestimation of irradiance the -s flag is used taking into account of the relief effect. The table 1 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 1: *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 the *mode 2* is selected the model gives the cumulative raster maps of **solar irradiation** (*beam_rad*, *diff_rad* and *refl_rad)* within a set day. Moreover it is possible to compute the 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 informations (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 2 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 2: *r.sun* output parameters

4.3 Adaptation of an 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 depends on the heating of the earth by the sun. The radiation from the sun is absorbed and reflected not homogeneously by the earth's surface because it varies with the geographic land distribution (land, water, forest, etc.) and with the time and the day (PETERSON & HENNESSEY 1978). For instance ice surfaces reflect the most part of sun light while the vegetation absorbs a great amount of light. This nonuniform heat absorption produces great 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 the moving air masses against the earth's surface slows down the wind speed from an undisturbed value at great altitude (geostrophic wind) to zero directly 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 of the turbulence phenomena. The presence of obstacles (like trees, rocks or buildings) produce a strong turbulence, which affects the efficiency turbines. Some local winds are instead generated by thermal effects like the difference in heating of the land and the water surfaces. The wind flows are influenced by small-scale topographic situations (e.g. mountain slopes facing the sun are heated more quickly) (ibid.).Therefore reliable wind data maps are needed to plan the use of wind turbines. To create the wind energy potential maps the wind speeds at 25 m with 1 Km resolution from the ground level were used. The data were derived from the Italian Atlas Wind Energy ("Atlante eolico italiano" 2002) developed by the Genoa University and the CESI research centre. Factors like the roughness (relief and land characteristics), the height above sea level and the 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 formula* (2) (HAU 2006), which is a conventional approach for describing the increase in wind speed with height:

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

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.

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

The formula assumes that the atmosphere is in neutral stability conditions, i.e. that the ground surface is neither heated nor cooled compared to the air temperature.

A simple description of the increasing wind speed with altitude is the power law approximation, which is sufficient for many engineering tasks (3):

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

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

The exponent α is usually assumed to be constant because it do not introduce substantial errors into the estimates (considering atmospheric layers < 50 m) if in the study area there are not trees or structures disturbing the 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 toward high level from the surface due to the presence of obstacles and finally the stability of the atmosphere (COUNIHAN 1975; TOUMA 1977). Even under neutral stability conditions, an exponent of 0.11 is more appropriate over open water (e.g., for offshore wind farms) than 0.143 which is more applicable over open land surfaces (HSU ET AL. 1994).

4.4 Adaptation of an existing methodology for identifying spatial geothermal energy potential

Geothermal energy is the energy stored in the form of heat beneath the surface of the solid earth. This definition became official in Germany (VDI 4640) and it has been adopted by the European Geothermal Energy Council (EGEC). A ground source heat pump can be defined as heating and/or cooling system that run by using the earth as a heat source (in the winter) or a heat sink (in the summer). Depending on latitude, the upper 3 meters of Earth's surface maintains a nearly constant temperature between 10 and 16°C (GEOBERICHTE 5 2007). In winter the heat pump extract heat from the ground and transferring it to the building. In the summer, the process is inverted so 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, and 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 are 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 the specific heat extraction values, that 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 varying 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), whereby the 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 to the mineral composition and granularity (sand or clay), the 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 considering the physical rock properties for the estimation of the specific heat extraction values, that corresponds to potential energy needed for the use of borehole heat exchangers (vertical loops). The regional geological map (1:250.000), the Corine Land Cover and a vector map for the soil suitability irrigation of Sardinia were used to identify the rocks types to 1.3 m for the horizontal loops. The geological stratification of rocks to 100 m for the vertical loops was derived using the regional geological map and the formula of Kaltschmitt that calculates the specific heat extraction (KALTSCHMITT ET AL. 2006). Based on the heat conductivity of the rocks the specific heat extraction capacity was calculated with the formula of KALTSCHMITT et al. (4) (KALTSCHMITT et al. 1999):

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

P_{EWS} = specific heat extraction capacity

λ = heat conductivity of the rock.

To obtain the estimation of the geological stratification Dott. Geol. Fausto Pani, freelance and Prof. Giovanni Barrocu, Cagliari University were consulted.

Two different types of potential maps for near-surface geothermal micro generation were obtained:

- Energy potential maps for borehole heat exchangers (vertical loops)
- Energy potential maps for horizontal ground heat exchangers (horizontal loops).

4.5 Developing a methodology for identifying the spatial biomass energy potential

Given the focus on housing development not every biomass is relevant but primarily wooden biomass which is suitable for producing heat and in addition electricity with the installation of cogeneration system. An important criteria for identifying the potential is the distance of the source of wood from the settlement and the capacity of the forest in terms of the wood reservoir. From an economic perspective the energy efficient use of biomass can be defined as the use of it within a radius of 30 km around a potential biomass facility (GERLINGER 2008: oral.). Because of the dimension of the eastern metropolitan area of Cagliari in relation to a radius of 30 km the range of efficiency was adjusted. In this case the energy biomass efficiency is related to an use in a radius of 15 km around a potential biomass facility. Furthermore it was not possible to include factors like road-types and –states as well as variable factors like 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 the use of wood is not permitted, all forest were extrapolated for constructing a raster map, which was used to calculate the theoretical energy potential for wood biomass energy. In order to identify the wood bioenergy potential a Monte Carlo method or simulation, a problem solving technique used in many fields of application to approximate the probability of certain outcomes, is used (KALOS & WHITLOCK 1986). The criteria for identifying the potential are the distance of the source of wood from the settlement and the capacity of the forest in terms of the wood reservoir. To differentiate between areas of varying potential in the eastern metropolitan area of Cagliari, a Monte Carlo-method was introduced.

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 which 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 it was used a **Monte Carlo integration,** which is a numerical integration using random numbers. Broadly speaking, Monte Carlo integration methods are *algorithms for the approximate evaluation of definite integrals, usually multidimensional ones* (UEBERHUBER 1997: 124) - in our case sum of forest areas. The usual 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).

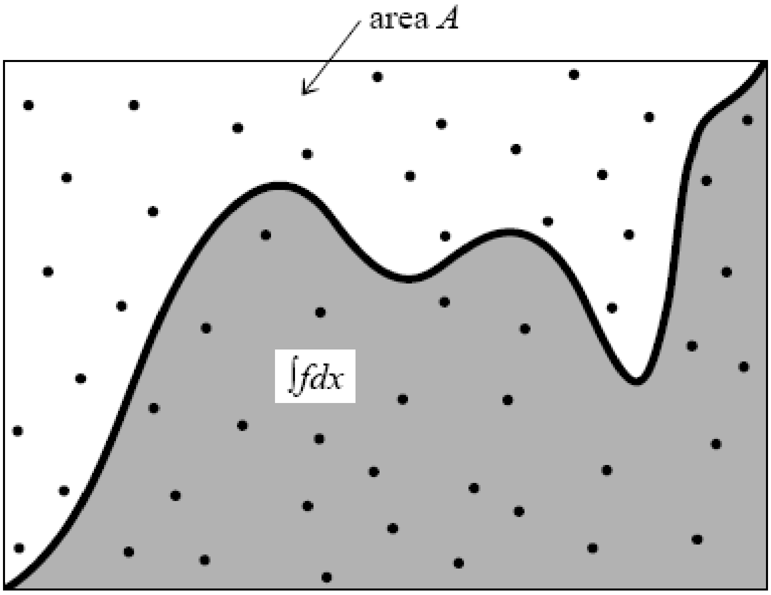


Figure 7: Monte Carlo integration. Random points are chosen within the area A (CHENEY & KINCAID 2004).

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 (formula 5).

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

This technique can further be implemented in multiple dimensions where the process becomes more useful. A rigorous evaluation of this technique finds the error approximately $\frac{1}{\sqrt{(N)}}$ which means $O(\frac{1}{\sqrt{n}})$ convergence (ibid.).

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

P_i= biomass energy potential; V_i= potential settlement

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

i=1, 2..,N; j≠i

Where:

A_j= Forests cells area

A= Total forest cell area

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

dij ≤ 15km

Tj= factor depending on transport and wood extraction cost

Using Monte Carlo Integration as in formula (6) it is numerically integrated the biomass energy potential according to two criteria: the presence of afforested areas (A_i) within the radius of 15 kilometres the distance between the potential location of the settlement and afforested areas (d_{ij}) (see Figure 8).

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)

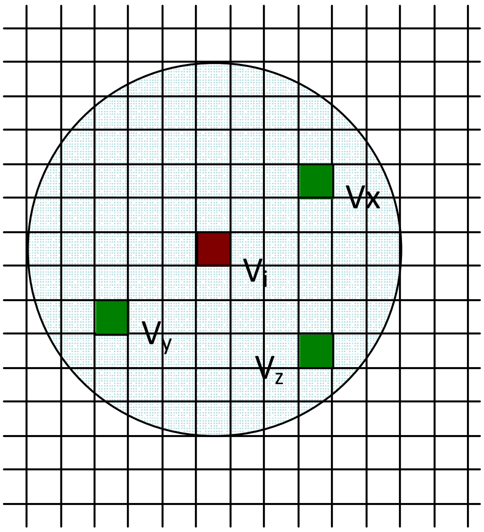


Figure 8: Implementation of the Monte Carlo Integration

Table 3 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	1:25.000	Region of Sardinia
	Protected areas Natura 2000 Sites	1:10.000	Landscape Plan of Sardinia

Table 3: Informations about the basis data used for the energy potential estimation

For each renewable energy we have realized the integration of data sets of different origin and with different resolution levels. A combination of all these data has enabled interdisciplinary analysis procedures and interoperability. Data were from multiple sources and at different scale. We have used vector data as well as raster data. Raster data had 90 m spatial resolution. The geological data, which were available, were vector data at 1:200.000 scale. Using these data, geothermal energy estimation has sense for regional level. However, there is not a big rocks types variability. Certainly, more accurate data produce more precise results. Other data (e.g. Land use, 1:25.000 and Protected areas 1:10.000) are accurate enough for the eastern metropolitan area of Cagliari.

4.6 Stakeholder survey

Decisions about siting or resource allocation require prioritizing multiple criteria. Different criteria were selected for assessing housing development in general as well as for settlements with micro renewables. In the second step a stakeholder survey was conducted in Italy, Germany and United Kingdom in order to involve expert groups in the selection of new residential areas with micro renewable technologies. This survey sought to gain insights into perceptions about new energy efficient settlement development. This required the participation of people who had expert knowledge about landscape and environmental planning and/or renewable energy and so the survey focused on students and academic planners, regional planners and public authorities. The experts which were students and academic planners and regional planners and public authorities from Italy, Germany and United Kingdom (min. 15 people for each category). A total number of 120 questionnaires were completed. Table 4 shows the number of respondents for each category and nationality.

	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 4: 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. The main reason concerns the results, because the author evaluates the new housing development on the basis of a strictly environmental point of view, which is lost in the calculation of the average of experts preferences. The second reason was that the writer has achieved knowledge about technical aspects of micro renewable technologies, environmental and landscape impacts, and planning issue related to their use which were useful by comparing the results between experts from the three countries. Through the survey, stakeholder experts expressed their preferences, that were converted into values. The weighting of a set of criteria in MCDM was achieved using a theory of measurement in a hierarchical structure, which is useful to take into account the relative importance of evaluation criteria (SAATY 1980).

This survey consisted of a questionnaire about renewable in residential development, which was distributed in person and by email, with participants returning the completed surveys in the same way (see Annex 1). The expert preferences were converted into values using pairwise comparisons methods, a procedure in the Analytical Hierarchy Process (AHP) (SAATY 1980). As input, the method takes the pairwise comparisons of the different criteria and produces their relative weights as output. According to the relative importance, the weights, which were assigned to different criteria, were calculated using MathCAD, an engineering calculation software. Consistency Ratios (CR) were also calculated to assess the reliability of the pairwise comparisons (ibid.).

The criteria were divided into factors and constraints (restricted areas). The maps were generated using a Boolean approach and a Weighted Linear Combination method (WLC) (MALCZEWSKI 1999:312). The Boolean approach is based on 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 favorite locations of new residential areas with micro renewable technologies according to expert stakeholder opinions.

The last step was to identify the optimal sites for new residential areas with micro renewables by combining the results obtained in the other steps. Different GIS-layers were overlaid to obtain the optimal sites for new energy efficient housing development according to the energy potentials and the 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 geographic information system (GIS) software products produced by ESRI. The ESRI Spatial Analyst extension enabled the user to create raster maps and analyze cell-based raster data. GRASS open source free Geographic Information System (GIS) was another software used for geospatial data management and analysis, image processing, graphics/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 the pairwise comparisons method. The 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 next higher 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 A (7):

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

The matrix has reciprocal properties, which are (8):

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

i, j= 1,…, n

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

In ideal case the comparison matrix (***A***) is fully consistent, the rank(***A***) = 1 and λ = ***n*** (***n*** = number of criteria). In this case, the following 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 we are looking for. When the entries a_{ij} changes only slightly, then 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 we are looking for the *eigenvector* which corresponds to the maximum *eigenvalue* (λ_{max}).

In order to obtain weights from calculated eigenvector the values have to be normalised by formula 10. (The weights have to sum up to 1.)

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

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 Eq. 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 Eq. 12.

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

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 Eq. 13:

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

Table 5 shows the value of the RI from matrices of order 1 to 10 as suggested by Satty. If $CR < 0.1$, then the comparisons are consistent enough. If, however, $CR \geq 0.1$, then the values of the ratio are indicative of 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 5: Random consistency indices for different number of criteria (n).

The 9-point scale used in typical analytic hierarchy studies is ranging from 1 (indifference or equal importance) to 9 (extreme preference or absolute importance) and is showed in Table 6.

1- ***Same*** importance
2- ***Slightly*** more important
3- ***Weekly*** more important
4- ***Weekly 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 6: Scale of relative importance for pairwise comparison.

The verification of the consistency ratio for the matrices in the questionnaire was done with MatCad. Table 7 shows that a total number of 120 questionnaires were completed, but only 108 were considered (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 7: 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 have been checked to verify the reliability of the judgment of the decision maker. In this study the consistency ratio is < 0.10, which indicates a reasonable level of consistency in the pairwise comparisons (Malczewski 1999). However 10 % of the pairwise comparison matrices (12 questionnaires) had to be excluded from interpretation, because the consistency ratio was ≥0.10.The inconsistency measure was useful for identifying possible errors in judgments in making pairwise comparison. AHP uses redundant judgments for checking consistency, and this 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 the 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 were 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 output of GIS based data processing and analysis to generate criterion maps (Malczewski 1999).

These maps were then be imported into the GIS for storing, followed by the allocation of weights to each layer and different scores to each attribute using the function of the Spatial analyst. In fact, 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. The result was then summed up producing a suitability map as shown by the formula (14)

Suitability Map = Σ [factor map (cn) * weight(wn) * constraint(b0/1)]   (14)

Where,

c_n = standardised raster cell,

w_n = weight derived from AHP pairwise comparison

b0/1 = Boolean map with values 0 or 1

n= number of raster cell

Finally, all the layers were overlaid to compose the constraints map. The outcome map showed the most and least suitable areas for locating housing development with renewable energy. The criteria were divided into continuous suitability factors and constraints (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 were combined to produce a single index of evaluation (EASTMAN 1995). This was realized by assuming that all the layers were of equal importance and therefore carry the same weight. This was achieved by summing up 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 and entering the ratings into a matrix. The procedure then required that the principle eigenvector of the pairwise matrix had to be 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 procedures is explained by the four points the 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 stakeholder, such as students and academic planners and regional environmental planners and public authorities from Germany, Italy and United Kingdom were asked with a questionnaire.

3. According to Stakeholders' preferences, different maps that translates the attributes into a measure of suitability were developed using 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 areas that are considered unsuitable for urban development.

In the WLC technique, factors are evaluated as fully continuous variables rather than discrete boolean constraints. For example, if the proximity to roads was considered important in a decision to locate 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 the 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, which had 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 the 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 the Natural Heritage
3. Conservation and development of cultural heritage (cultural landscapes, cities and towns, natural and historic monuments)

To maintain the urban and rural diversity of the EU the goal is 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 (air, water, soil) and protection of definite areas (protected areas, environmentally sensitive areas).

To preserve the variety of the European identity the combination of coherent conservation strategies with economic and regional development needs is required, otherwise the heritage of the EU could be endangered by economic and social modernization processes.

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. Regarding to housing development the Plan prescribes to allocate the new development close to built-up areas. On the other hand, to preserve biodiversity and the cultural heritage, landscape protected areas have been established and also the natural and semi-natural areas should be protected (e.g. forested areas).

Furthermore, the **City of Hannover** has devised and applied basic guidelines toward to a sustainable and environmentally compatible settlement development and an effective urban environment management systems (CITY OF HANNOVER 2004).

The residential development in Hannover is based on two principles: minimizing the traffic and sparing the country side. The urban planning is oriented on ecological objectives:

- sparing use of building land (high density and good quality accommodation, space-saving building form sand access facilities, multiple use of areas, mixture of uses)

- priority for local public transport (e.g. high-density development along tram routes)

- urban greenspace (e.g. conservation and enhancement of the countryside)

- 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 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 which are suitable for urban development at regional level. The potential and the type of land use need different socio-economic and environmental studies (MILLER ET AL. 1998). Identification of criteria is a technical activity, which is based on theory, empirical research or common sense. Criteria identification can be done via a participatory approach by a group of experts from various disciplines. In this work, criteria were selected by the authors in order to determine the appropriate land for urban expansion: 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) and the slope gradient (see Table 8).

Clearly, each criterion should be carefully examined and probably adjusted with respect to the local conditions and also many physical factors such as topography, soil and others should be investigated in the location where the possible urban development will take place. 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 can be considered at bigger scale.

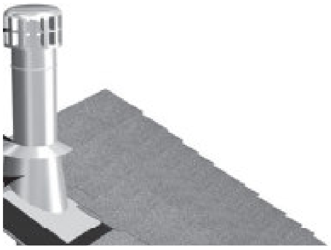
Factor/Criteria	Type	Description
Proximity to existing urban areas	Planning factor (Compact Development)	The distance to existing urban areas is important because the significantly impact moving costs, so the locations must be adjacent to built up areas (A G-O YEH 1999)
Proximity to major roads and train lines	Transport factor	The roads are an important factor in housing development because their presence indicates human activity (A G-O YEH 1999).
Distance from environmentally valuable and vulnerable areas or from protected areas	Environmental factor	The distance from environmentally areas is an important factor in order to create buffer zones and reduce the development impact on the valuable and vulnerable areas (e.g. the Molentargius wetland) (CF. UNESCO, 1974; 1995).
Proximity to water (lakes and rivers)	Attractiveness factor	The amenity value are provided by green spaces and water bodies to improve the urban environmental quality (JIM & CHEN WENDY 2006). This factor is relevant from the point of view of assessing and incorporating it into urban planning and development.
Slope gradient	Physical factor	The slope factor is important because areas with exceeding 10 % are usually not suitable for residential development (CHAPIN AND KAISER 1978). The optimal areas for housing residential use are areas with 2-6 % slopes.

Table 8: Criteria for housing development.

4.6.5 Selecting criteria for micro generation

The criteria for the expert survey shown in Table 9 focused on landscape and environmental impacts, because technical factors were included in the potential maps. Criteria, identified for new settlement with micro generators, were separated from the first ones selected only for new settlement. This choice can be explained by decomposing the new location in two different layers. For the location of new settlement with micro renewable technologies different criteria were thus identified.

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 and in sensitive landscapes (cultural heritage and protected areas). The impact depends on their design and where they are located (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 the historic/cultural landscape. Impacts depend on many factors: proximity to neighbors, local terrain, and tree coverage (English Heritage 2008). Building-mounted turbines will usually 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, also in urban areas, which could result in injury or mortality of bats and/or birds. 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 the bird's biodiversity protection. The foraging habitat requirements for bats are different. However, potential effects on foraging habitat can be minimized through 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 in particular near landscape protected areas (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 more above the height of the roof, this can affect views or can break the profile of the home[1]. This effect should be considered in particular near protected areas or cultural heritage 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 near it. 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

[1] It is necessary to have a flue which is specifically designed for wood fuel appliances. Roughly on a 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).

			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 a borehole and accessible to digging machinery. To install a loop system firstly a vertical bore holes are drilled 50 to 100m deep and 30-60 cm in breadth so it is important to verify the presence of aquifers which is in many cases difficult, but can cause several problems (see the case of Staufen, Germany)[2].
Geothermal Horizontal Loops (GHL) 	Distance from historic/cultural features (historical centre, areas of historical and cultural interests, archeological sites)	Cultural heritage factor	Like for the vertical loops it is necessary to bore so it should be paid attention to archeological areas (see geothermal vertical loops).
	Distance from flooding areas	Technical factor	This factor is the only one which concerns the damage to the loops caused from a flood, in areas characterized by flooding risk (JENSEN 2010, or.).

Table 9: Criteria for micro renewable technologies.

[2] In the historical centre of the city of Staufen im Breisgau (Germany) a project was planned to ensure the energy production from geothermal energy using vertical loops. While the works were in progress, the escavations penetrated deeper artesian aquifers that could infiltrate into the open boreholes. With a good probability layers of the Gipskeuper-Formation have been drilled through. The Gipskeuper contains typical anhydrite that in contact with water reacts to gypsum which causes volume extension of about 61 %. The swelling process once started cannot be stopped easily because the process itself opens and closes water paths. The effects are that a lot of buildings (150) have been involved with cracking and other effects of differential swelling movements beneath the foundation (SASS ET AL. 2009).

Criteria were identified according to data availability. Clearly, for future research improvements other criteria can be identified and integrated. In this work except for the DEM, all other data, used to identify expert preferences, were regional data at 1:10.000, provided by the Region of Sardinia. These data have uniform scale and were also used to build the Regional Landscape Plan. Therefore, it can be noted that they were almost updated. In this work we have converted these vector data (areas, lines and points) into the raster using the GRASS command **v.to.rast**. to obtain the continuous maps according to experts preferences. In this step of the procedures both software GIS ArcGIS 9.1 and GRASS GIS were used in a complementary way, because GIS ArcGIS works better on vector data and on the contrary GRASS GIS on raster data.

Table 10 shows criteria and 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	European Environment Agency (CORINE Land Cover 2000-Program)
	Valuable landscape areas (.shp)	1:10.000	Landscape Plan of Sardinia

Table 10: Informations about the basis data used for the suitability maps

Restriction areas were applied after prioritizing criteria by experts. The constraints were: built-up areas, water (lakes and rivers) and areas characterized by hydrogeological instability. These data were available and consisted of a data set, which stem from different sources and at different scale. Regional data have not all the same 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. From the study areas with 3.-4. hazard/risk evaluation were excluded.

Table 11 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 11: Informations about the basis data used for the constraints 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 a population of 322.392 inhabitants in 2009 (ISTAT DATA 2010, WWW). Cagliari is the capital of Sardinia, situated at the southern shore of the island at the "Gulf of the Angeles" (*Golfo degli Angeli*). 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*.

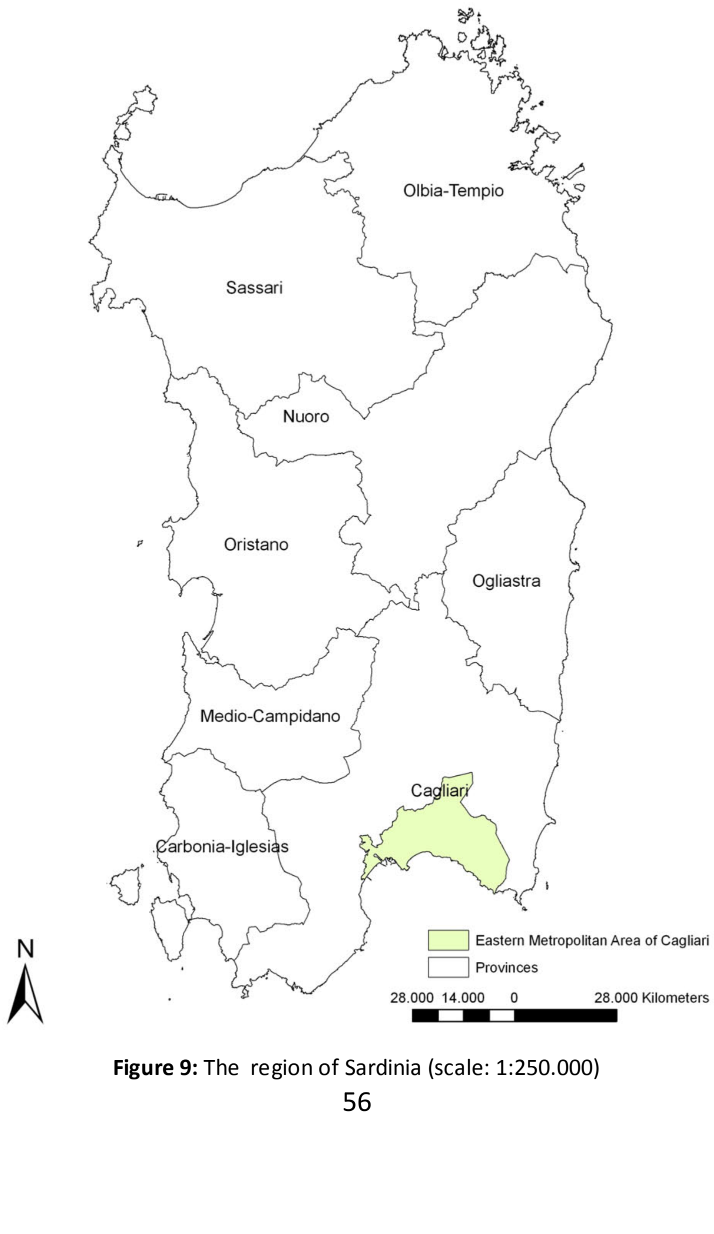


Figure 9: The region of Sardinia (scale: 1:250.000)

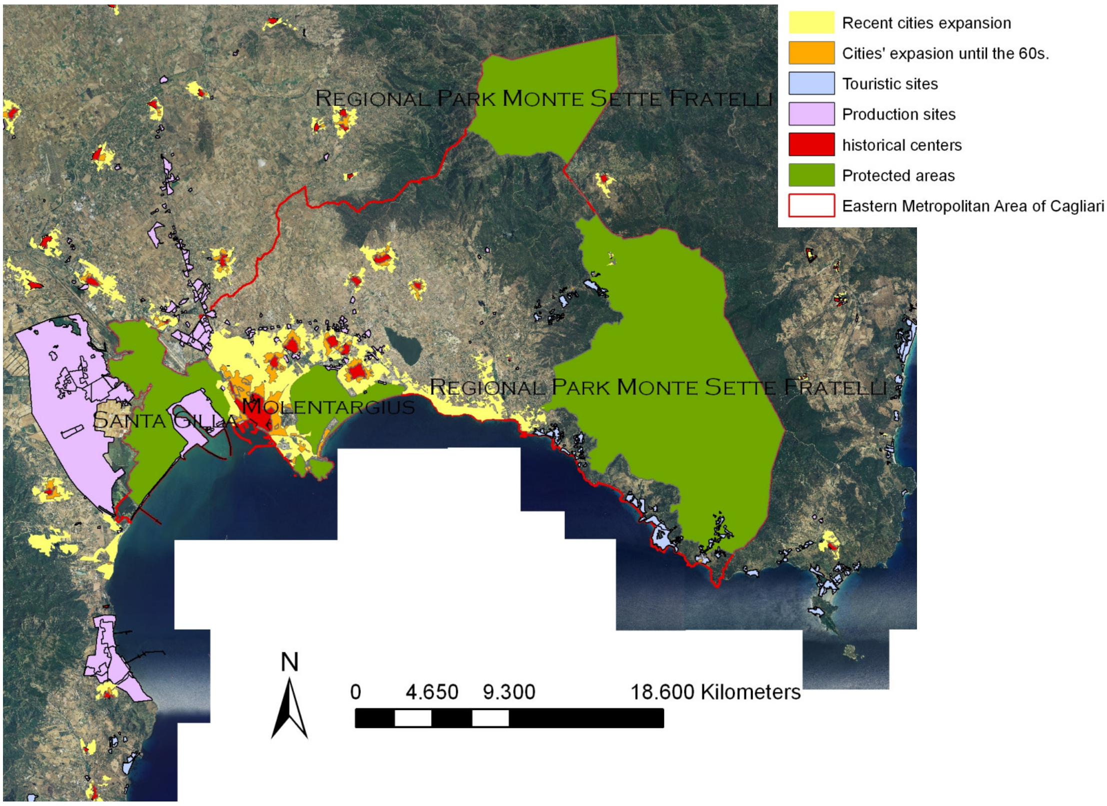


Figure 10: The Eastern Metropolitan Area of Cagliari, Sardinia (scale: 1:250.000)

This area is chosen as an interesting case study because of presents favorable conditions for the application of a renewable energy mix. Also the land demand for settlements, traffic infrastructure and tourism development has been high from the end of the 60'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 for fulfilling the growing demand for housing and infrastructure, to exploit opportunities for renewable and decentralized micro energy production, as well as to respect 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 the recently published Sardinian Landscape Plan ("Piano Paesaggistico Regionale" 2006) that was drafted in Sardinia as the first region in Italy responding to the European Landscape Convention (COUNCIL OF EUROPE, 2000) and the landscape national legislation ("Codice Urbani" 2004). The study area's ecologically most relevant site and **treated by the growth of the urbanization** is the Molentargius wetlands, recognized by the Ramsar convention and Natura 2000. It is nationally protected as a *Parchi Regionali* (cf. FEDERPARCHI 2009), a conservation designation that covers areas with a special value for nature and environment and cultural significance for the local population (cf. MINISTERO DELL´AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE 2007, www).

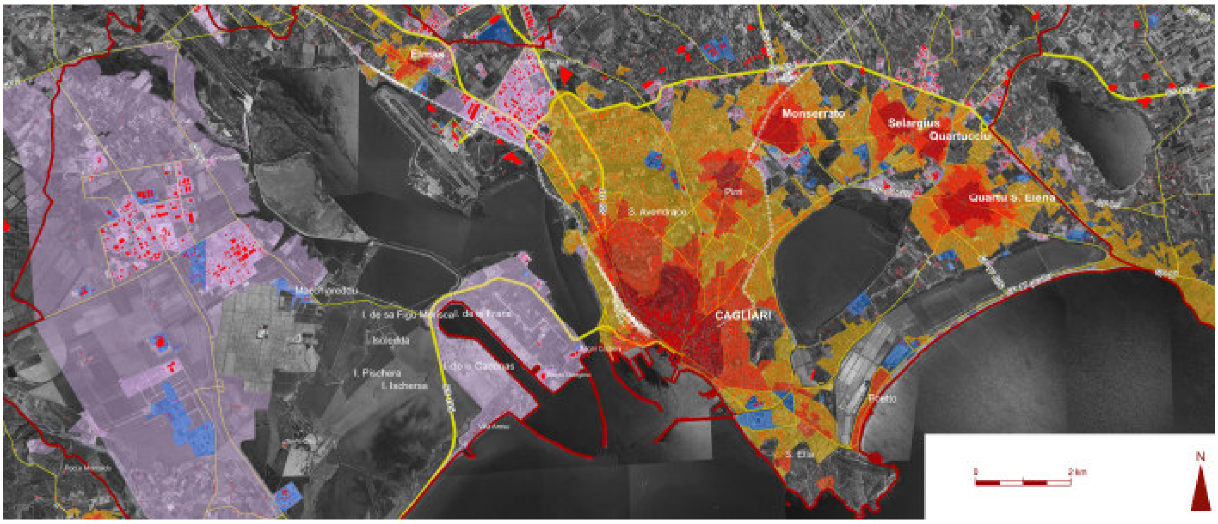


Figure 11: Increasing demands for settlement in Cagliari (deep red = ancient centre, orange = extensions until the end of 1950s, yellow = urban enlargement since 1960, magenta = trade and industry, blue = areas of touristic importance).

5.2 Landscape planning in Sardinia

The landscape planning in the region of Sardinia is based on the protection of landscapes and recovery of identity values, which characterize urban, development, production, historical and cultural sites. The Regional Landscape Plan of Sardinia ("Piano Paesaggistico Regionale"- P.P.R.), approved by the Region in September 2006 for the coastal areas. The P.P.R. of Sardinia has opened the way for the application of the principles of the European Landscape Convention (ELC) signed by Italy in Florence in 2000 and it is the first landscape plan approved in Italy after the national Degree called "Urbani" of 2004. According to this, the rules of the landscape plan encompasses the entire region, where the landscape plays a crucial role by defining strategic objectives, methods and contents of the planning at sub-regional and local levels.

The most innovative aspect of the landscape plan, compared with the regional previous planning, is about the management and the control of land transformation processes: the plan assumes as main objective the landscape protection based on the preservation of environmental and cultural values in the territories, which are not modified by human activities or urbanization. This trend, expressed through the principle of landscape protection, is combined with other principles, e.g. 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. On the other hands, all un-built places of the coastal area without any transformation, according to the P.P.R. objectives, are to remain intact. This is due to the fact that since 1960s the coastal area was exploited for touristic use, locating without planning control new buildings (cf. MANCA, 2009).

The landscape plan introduced a further definition, the "coastal zone" defined as a set of strategic resources and of relevance, where environmental, cultural and human factors are strictly interrelated. New building are to be planned near urban centers, where the PPR allow to develop new opportunities for tourism reducing the urban pressure along the coast. To reduce the urban sprawl, in the country side there are severe limitations in building size in relation to the properties and agro-forestry and pastoral activities. However, the P.P.R. identifies strategies for restoring amenities compromised by many phenomena, such as the abandonment, the land uses incompatible with the character of places and the indiscriminate use of resources. The Plan proposes to apply the principle of minimum use of land for the irreversible transformation resulting from new developments. In addition, it is forbidden to built within 300 meters from 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 modes of reading the territory, three ways of defining the elements composing its identity: environment, history and culture, settlements. These three readings allowed identification and regulation of the assets and components of the landscape belonging to each of the categories chosen. But clearly within the actual landscape each element is part of a given context and in that context it enters a particular relation with elements belonging to other categories (MANCA 2009). For this reason the landscape analysis is completed by identifying 27 landscape domains, for which a detailed analysis was conducted. Every domain enfolds a project idea for future transformations, which is made explicit by several directions for the local community, e.g. municipalities through the land use plans, to keep (BIGGIO 2009). The directions constitute the general objectives, and they are purposefully kept 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

The landscape domains 1 "Gulf of Cagliari" ("Golfo di Cagliari") and 27 "Eastern Gulf of Cagliari" ("Golfo orientale di Cagliari") cover the case study area. The directions for both landscape areas are to localize new residential areas near built-up areas and to avoid settlement development on coastal zones. This fact is connected with the purpose of restoring historical centers and containing cities expansions. The regional landscape Plan it is environment- oriented on connecting and preserving sensitive areas such as the Molentargius wetland, S.Gilla, the Poetto Beach and the Monte Sette-Fratelli Regional Park. In particular, the presence of two wetlands of international and community importance within the metropolitan area of Cagliari, where a quarter of inhabitants of Sardinia are concentrated, poses difficulties for the management of the coastal wetlands and for updating urban and landscape planning (SCHRENK 2009). Both wetlands contribute to the generation of eco-systems with a delicate balance from several perspectives. Hence the wetlands have a significant impact on the micro-climate and affect the quality of life of the urban areas around them (ZOPPI 2009)

The Molentargius wetland includes different habitats from 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 Bellarosa basin contains fresh and brackish water separated by an ecological filtration system and are an important habitat e.g. for (in parts domestic) flamingos. The former Molentargius saline filled with salt water is home for various halophytes. Finally the Poetto beach has to be mentioned as a major habitat for a huge range of waterfowls. Beside those well known and 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, many illegal buildings have surfaced, nullifying the desire to preserve the area. In particular, municipal administrations did not take any initiative to enforce the conservation rules, changing the natural environmental vocation of the area. In the area of Is Arena, known in the city of Cagliari as Medau su Cramu, are several instances of illegal buildings, abandoned quarries, and illegal dumps. This area is characterized by fields of forage, eucalyptus, olive threes, vineyards, tree lines, brush vegetation.

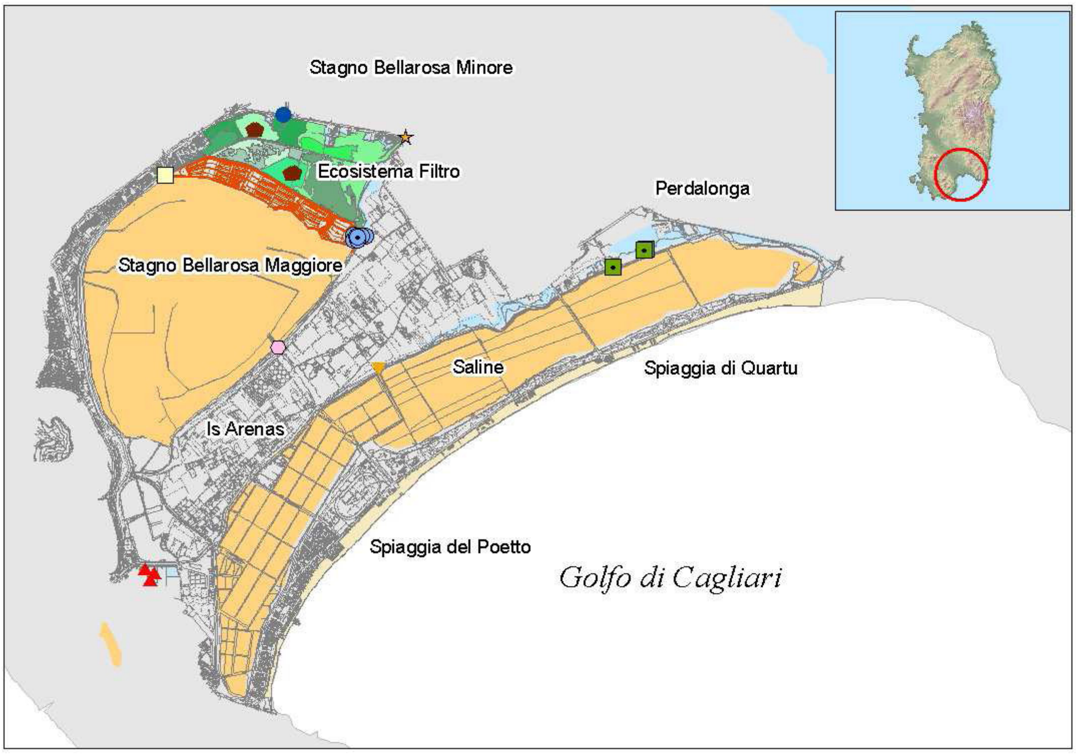


Figure 12: Molentargius wetland

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

In this work to calculate the preliminary solar energy potential for 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, a digital representation of the ground surface topography, was used as input to create the slope and the aspect maps (see Figure 13).

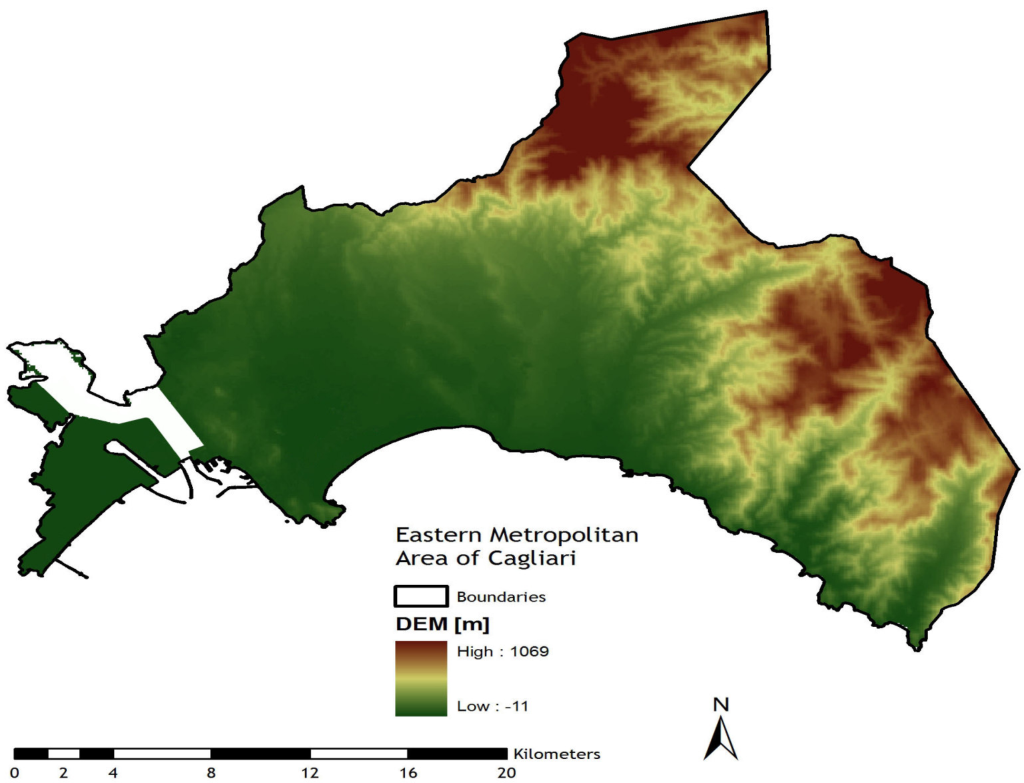


Figure 13: Digital Elevation Model 90 m resolution, scale 1: 250.000

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

The parameter aspin describes the angle in which a terrain surface differs from south 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, accordingly, an Azimut of +90° means a western alignment. At -45° or +45° the it is directed southeastern or southwestern (GROßKOPF O.J., HEINDL INTERNET AG 2009). The figure 14 shows the aspect for the eastern metropolitan area of Cagliari.

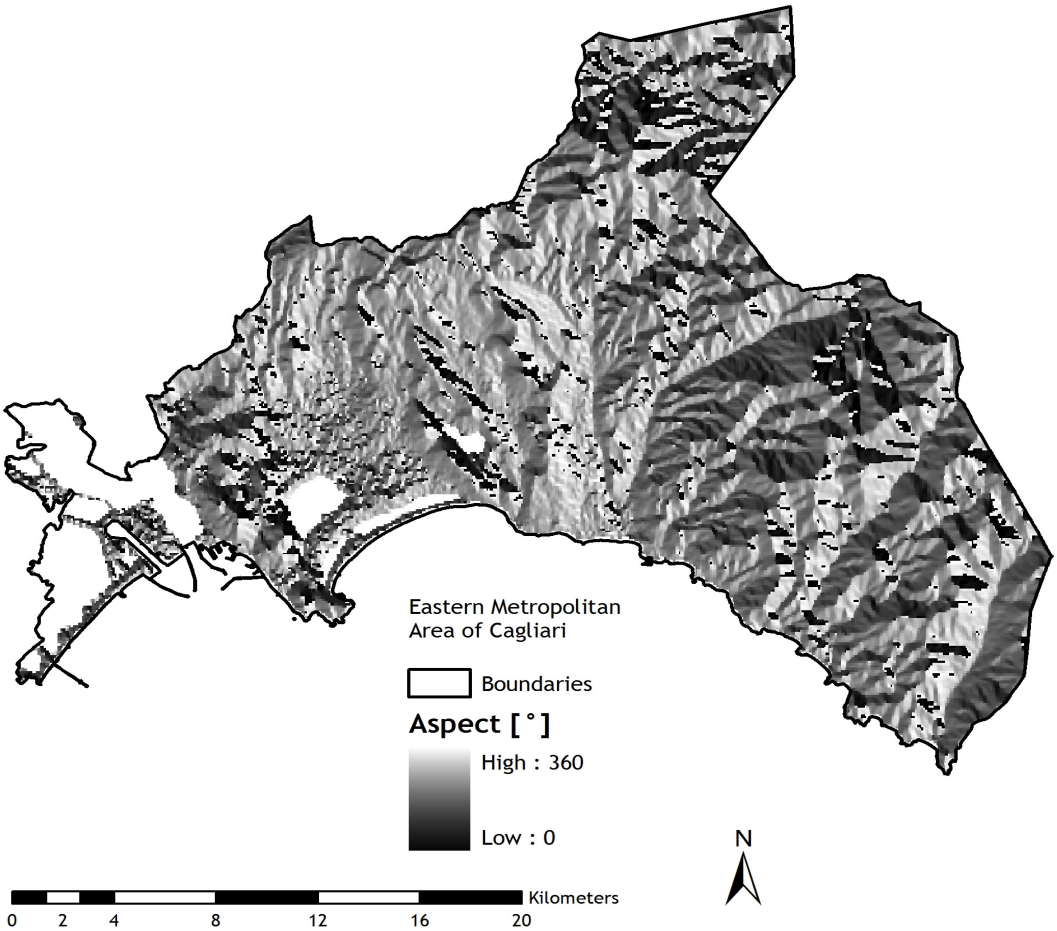


Figure 14: Aspect or Azimuth-angle of the terrain, scale 1: 250.000

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.

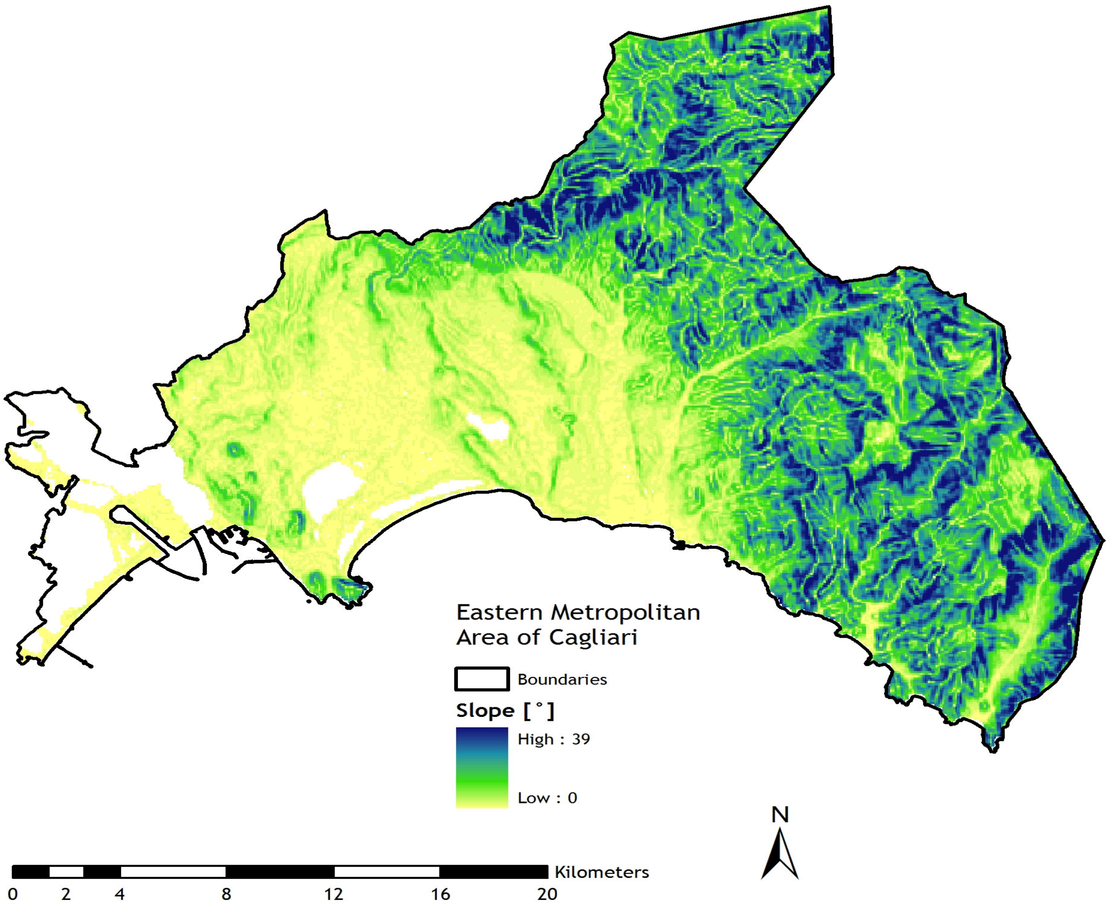


Figure 15: Slope of the terrain, scale 1: 250.000

Both Azimut and slope depend on the geographical latitude. According to the latitude there is a different solar altitude and therefore solar radiation faces –depending on the latitude- in a different angle on the terrain surfaces. Azimut and slope need to be chosen regarding this phenomena to achieve the greatest possible capacity.

Landuse in the eastern metropolitan area of Cagliari

The eastern metropolitan area of Cagliari is prevalent characterised by rural areas which are located around the capital city Cagliari and surrounded smaller cities. Different to urbanized districts, this suburban sprawl contains a huge land use allotment of agriculture (around 46.72%). Other land uses, such as residential, commercial and industrial areas cover about 40 %. While forest areas cover just 5.39%, the remaining part of the surface is distributed on 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.

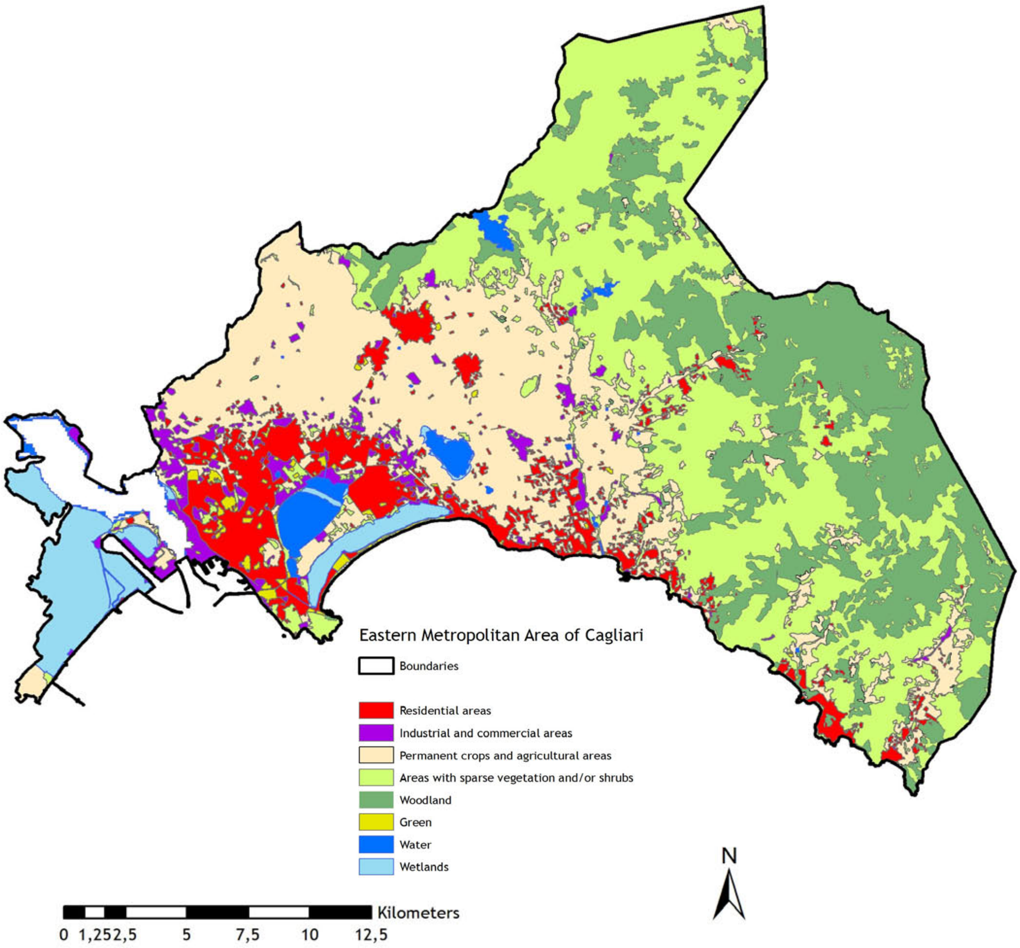


Figure 16: Land use, scale 1: 250.000

Reflectance of the earth's surface (albedo)

The reflectance of surfaces is called albedo. It describes the relation between reflected and absorbed solar radiation. This parameter is important to calculate the irradiance of the sun on flats. Because the usable energy potential of the sun rays depends on how many rays are absorbed, reflected or transmitted. As 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), on the contrary a water expanse has an amount of reflection of 5-15 % (albedo=0,05-0,15). Due to this fact an albedo of 0,2 is presumed, which is an average value valid for rural city areas (SÚRI & HOFIERKA 2002).

Linke turbidity (linkein)

The turbidity of an atmosphere depends on various factors such as the dispersion on molecules in the air, absorption of steam, ozone and carbon dioxide, dispersion and absorption on aerosols (dust and waterdrops) (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 means, 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- great intense within a region; the value of an absolute clear atmosphere is 1,0 (SÚRI & HOFIERKA 2002). Polar air has the lowest factor of turbidity (1,9), tropic air has the highest turbidity factor (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 with an accuracy of 3m. The latitude was computed directly from the DEM raster, while the albedo and the linke turbidity were supposed constant all over the 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 gave the cumulated maps for every month and finally for the whole year dividing by the month duration it can be obtained the monthly average (see Figure 17). The daily maps are calculated by the sum of reflected, diffuse and beam radiation using the function **r.mapcalc**. By generating raster maps the most critical issue is the linke turbidity factor as its estimation is still prone to large uncertainty and the clear-sky indexes were not available. In this case the solar irradiation for the eastern metropolitan area of Cagliari was overestimated, because it did not take into account cloudiness. Furthermore the Linke turbidity index in this first approximation was considered constant. On the contrary, it varies over the region.

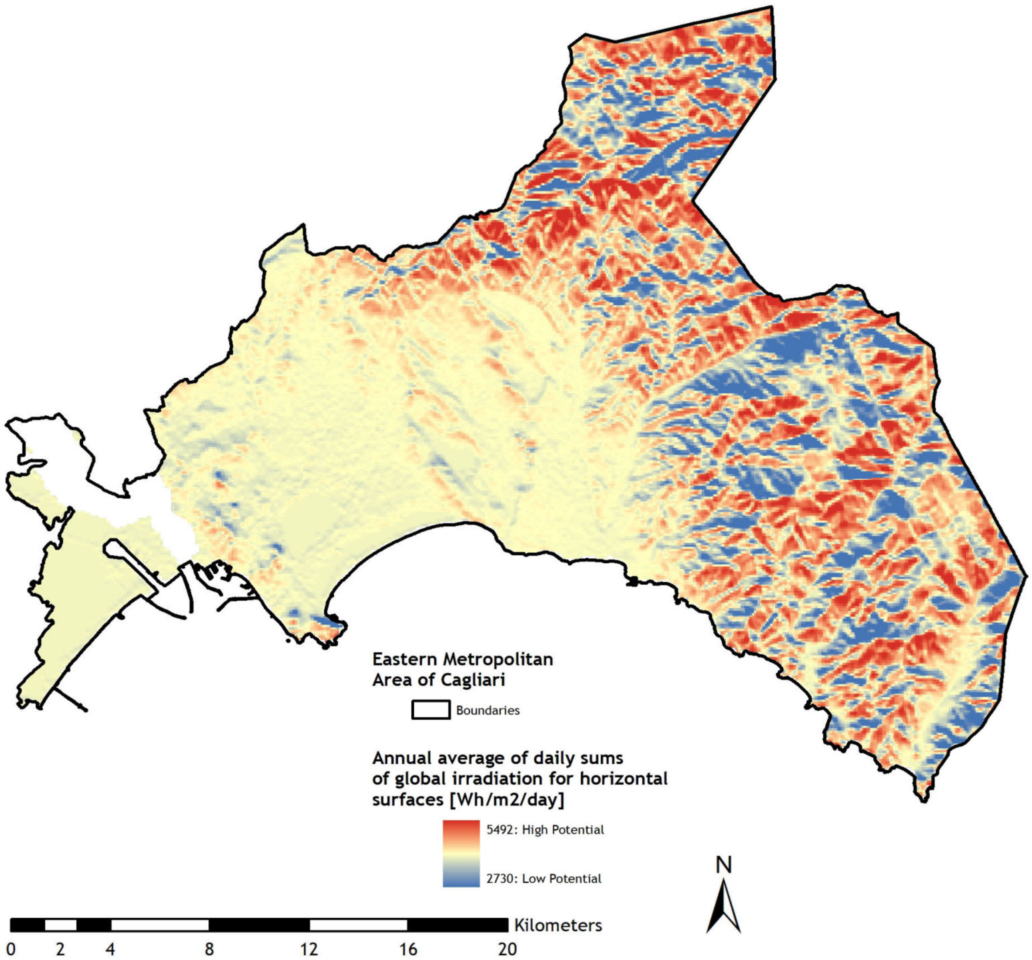


Figure 17: Annual average of daily sums of global irradiation for horizontal surfaces [Wh/m^2/day] for clear sky conditions, scale 1: 250.000

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 get the final distribution out of the spatial distribution of the preliminary solar radiation potential.

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

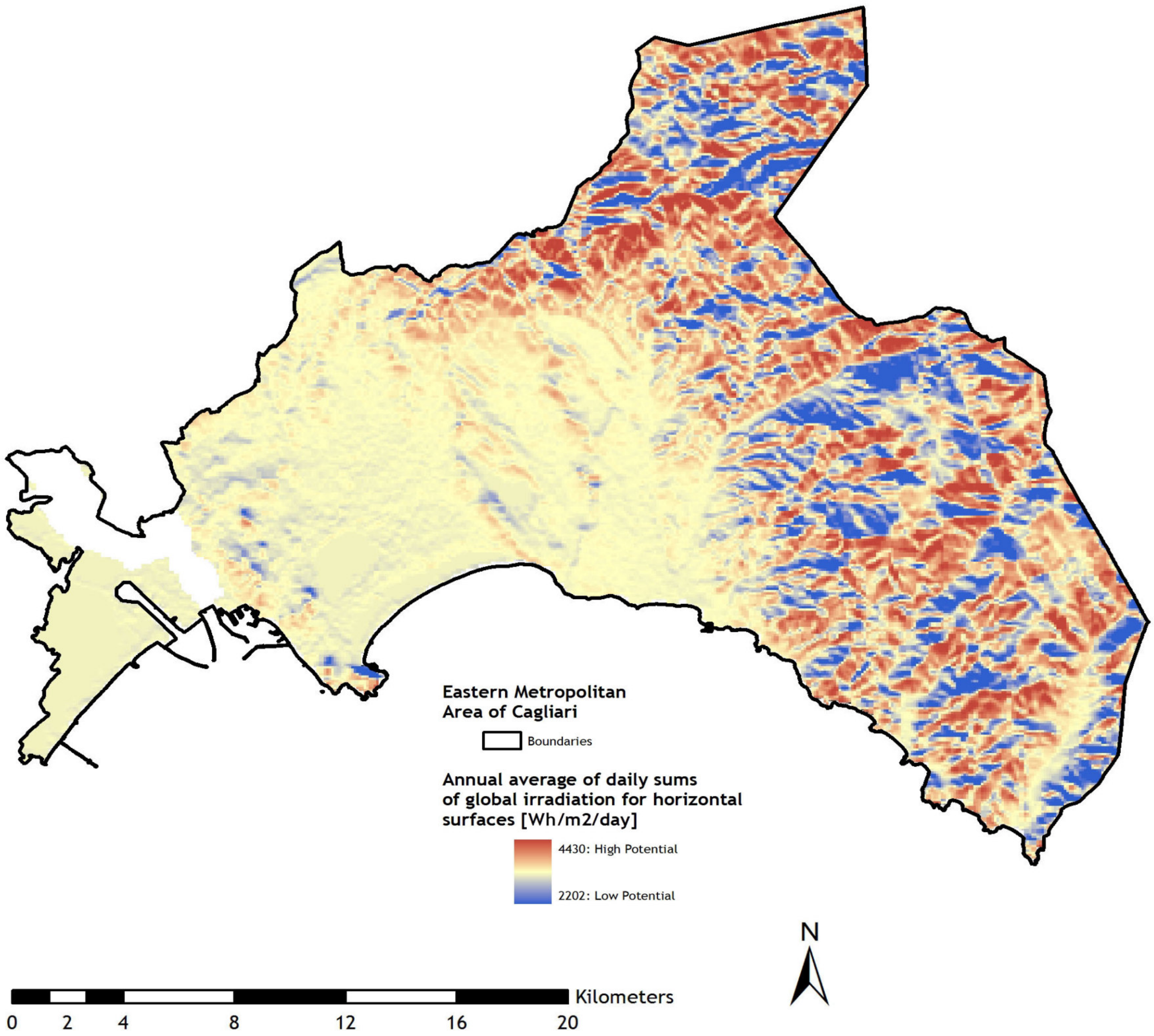


Figure 18: Annual average of daily sums of global irradiation for horizontal surfaces [Wh/m^2/day], scale 1: 250.000

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

The wind speeds were calculated using a formula (COUNIHAN 1975; TOUMA 1977) that took in input the wind speeds at 25m and the Digital Elevation Model and gave as output wind speeds 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 from the ground level. We have assumed that for each cell in 1-km raster resolution these factors remain constant.

Input parameter and outputs

In this work the following input parameters were used to calculate the 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)
- wind average speeds at 25 m from the ground level that refer to a grid of about 1x1 km from the Italian Wind Atlas 2002

Processing data

The initial 90 m DEM was corrected to avoid negative aids above the 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 an interpolation the 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 formula was applied to obtain final average wind speeds raster map with a resolution of 90 m (see Figure 19).

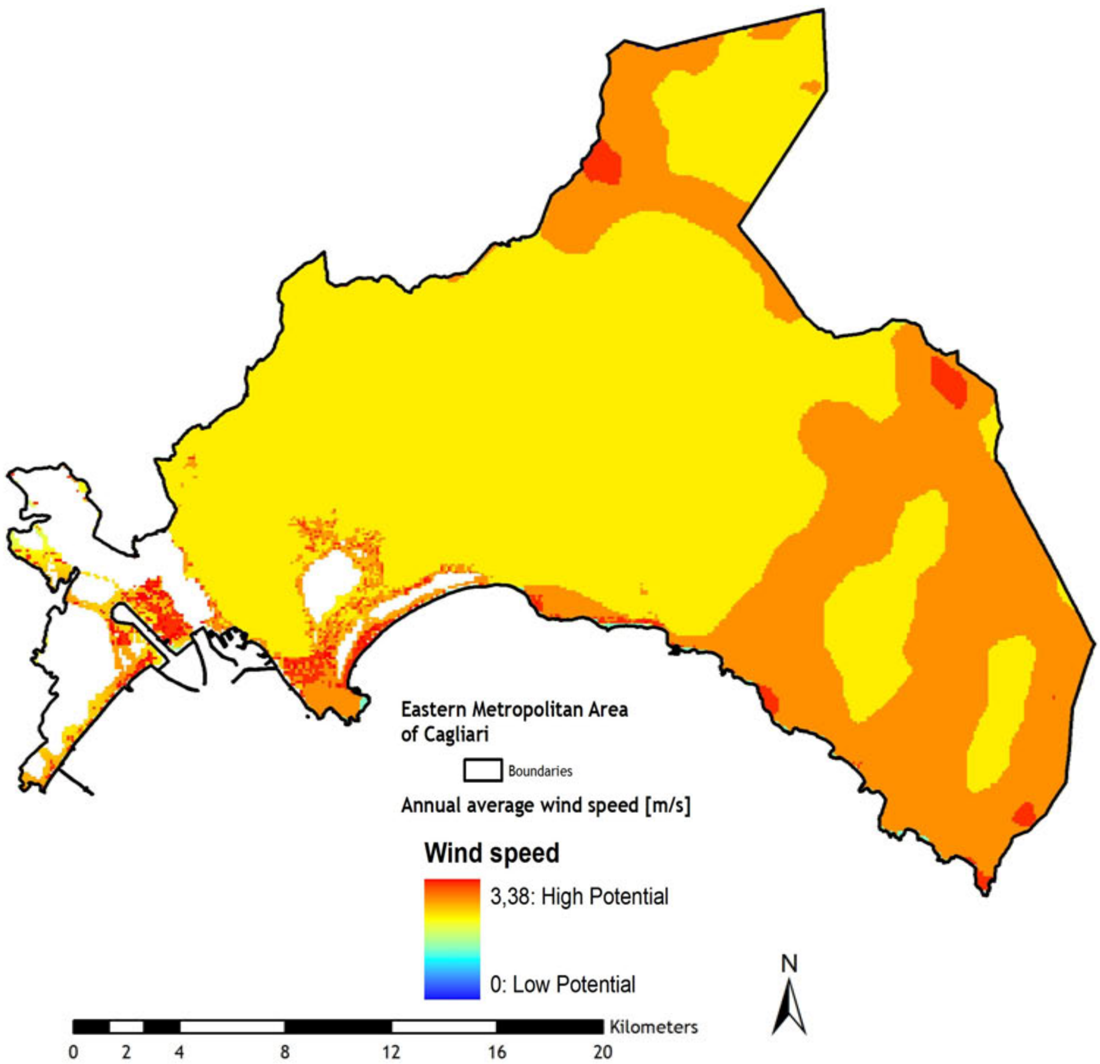


Figure 19: Wind speeds [m/s], scale 1: 250.000

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 in a depth of 100 m the soil was divided in two homogeneus layers: unconsolidated and solid rocks. For the unconsolidated rocks there were not comprehensive data at the detail of planning requirements, then the thickness sometimes is only a rough estimate. The data for solid rocks were more accurate. The information about ground water flow component was not considered (in according to VDI 3640 German directive). Especially 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 the 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 the basis for the dimensioning of ground coupled heat pumps.

The conditions are:

- only heat extraction
- Length of the individual borehole heat exchangers must be between 40m and 100m
- Smallest 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 input (see Figure 20). This map was consulted to evaluate the specific heat extraction capacities, because it describes the different types of rocks which were then combined by values from literature with regard to specific heat conductivity.

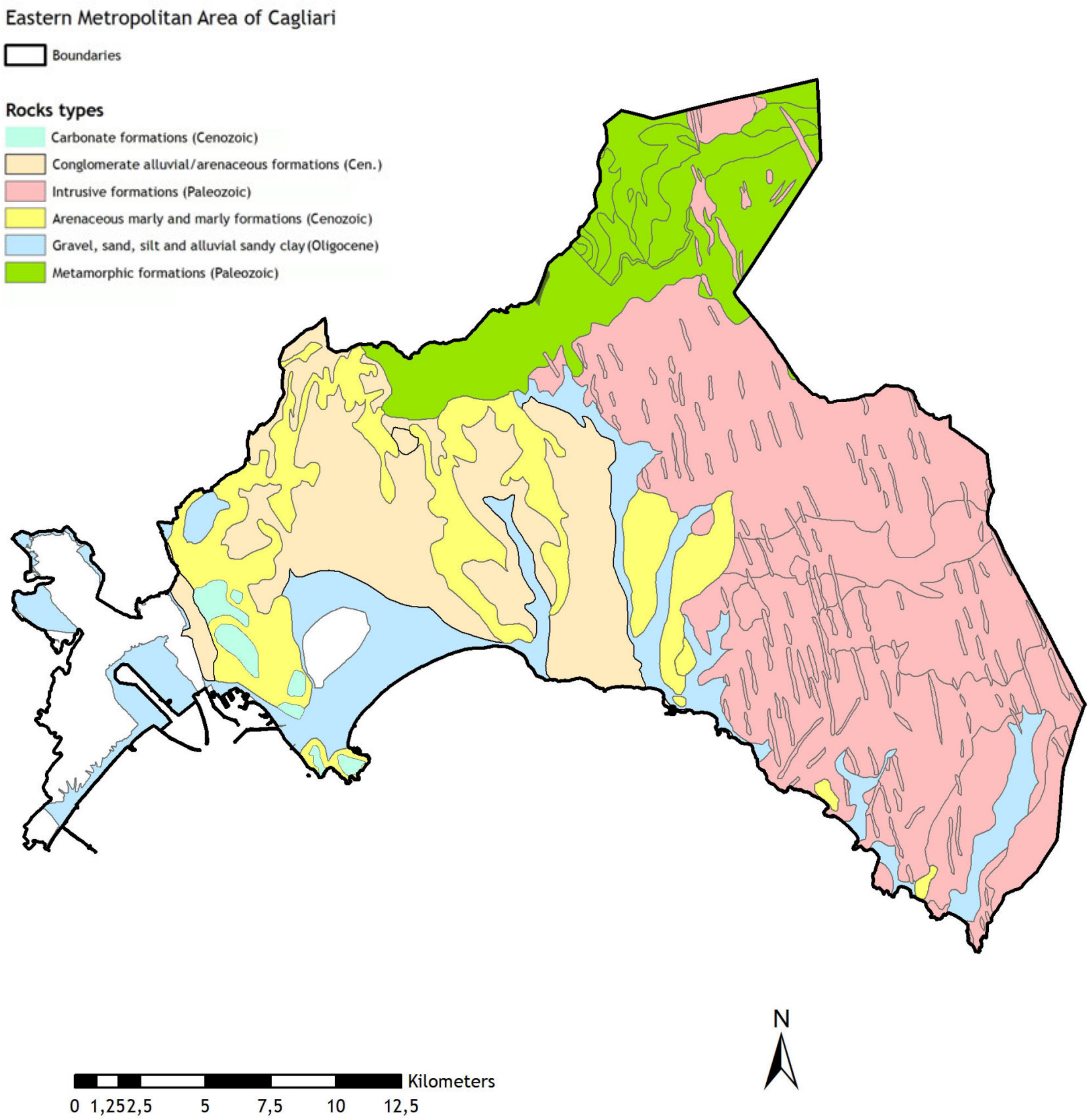


Figure 20: Geological map, scale 1: 250.000

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

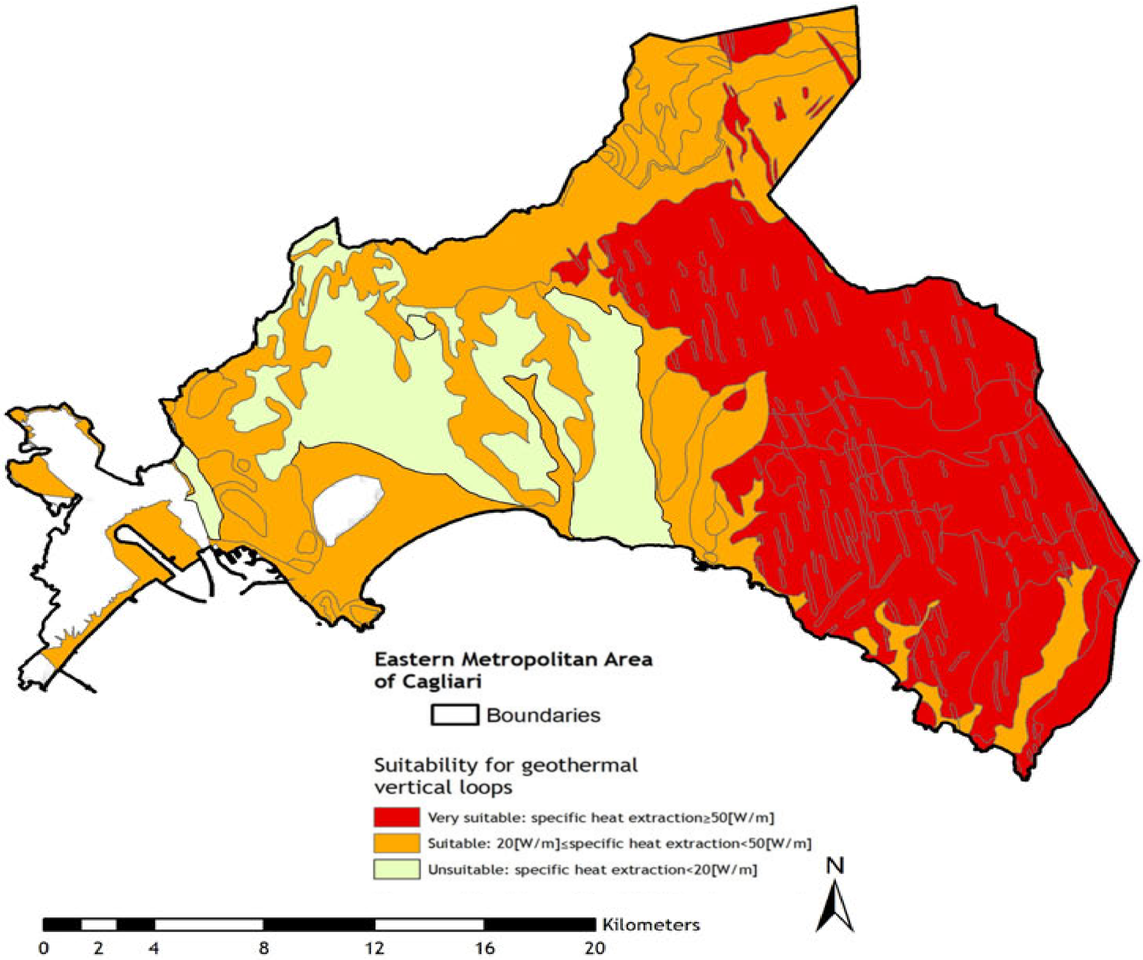


Figure 21: Geothermal potential estimation for vertical loops, scale 1: 250.000.
The unsuitable areas are for economic reasons.

Energy potential map for borehole heat exchangers (horizontal loops)

The geological map, the map for irrigation and the land use map were considered to select the suitable and unsuitable areas for the installation of horizontal loops. The first one was consulted like for the vertical loops to evaluate the specific heat extraction capacities. The second map was useful to evaluate the presence of soil (up to 1.3 m) taking into account the land classification proposed in a soil survey, a work commissioned by the Region of Sardinia in 1986 about the suitability for irrigation and therefore for agriculture use (ARU ET AL. 1986). The land use map was helpful by selecting agricultural areas and is used in combination whit the irrigation map that shows the arable and not arable areas for the region of Sardinia. The soil which is suitable for agriculture is a very small part of the land of Sardinia, but has an high perceptual in the case study area. On the other hand, considering the big variety of soil conditions (e.g. evapotraspiration) and characteristics (e.g.

presence of aquifers), soil types and the missing of quantitative informations and data about all these factors (ARU ET AL. 1991) it was possible at this scale to give a qualitative potential estimation for the use of horizontal loops. For more precision it is necessary to conduct further specific studies on site and local analysis that are required for the planning and design of horizontal loops.

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

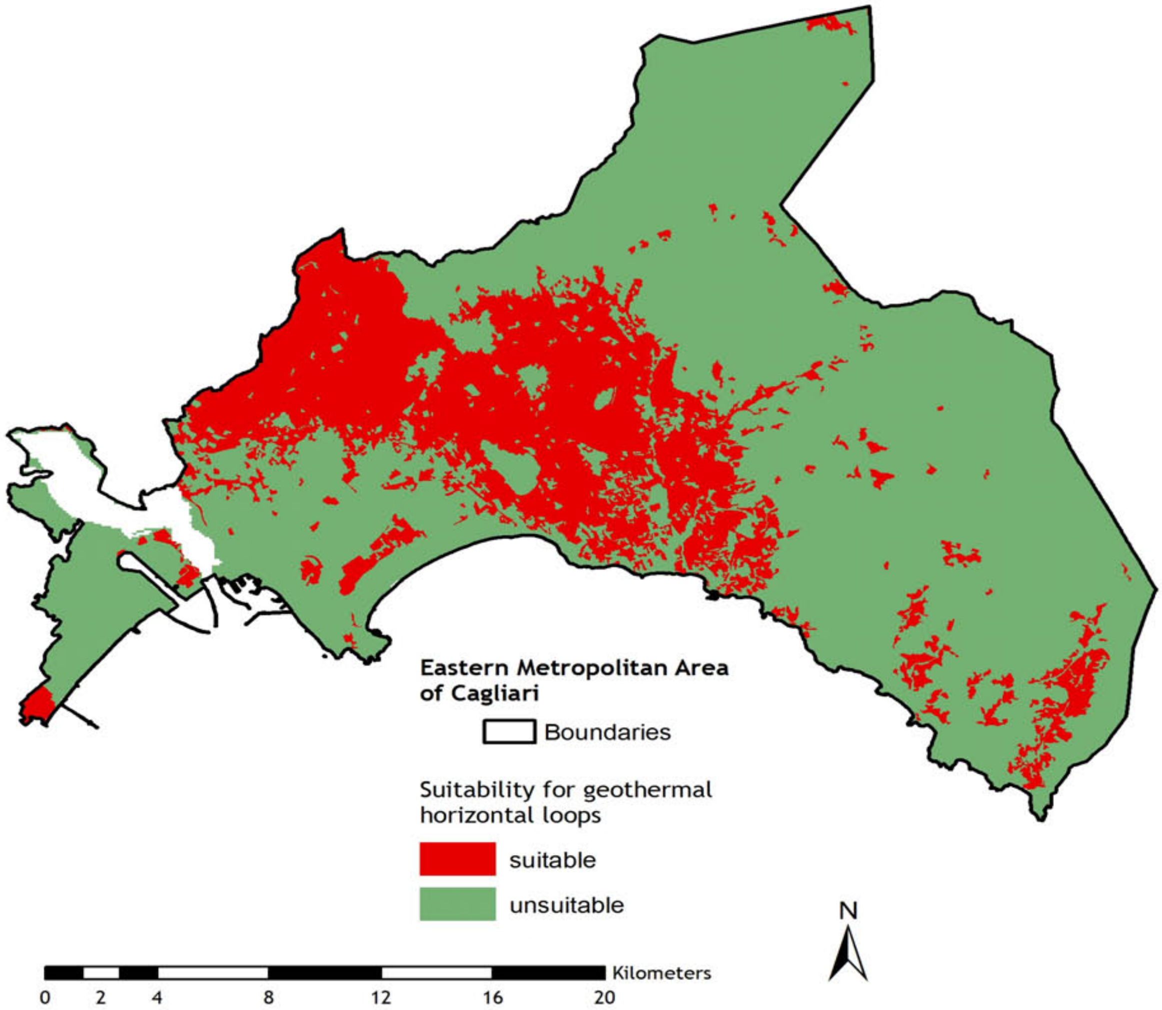


Figure 22: Geothermal potential estimation for horizontal loops, scale 1: 250.000

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

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

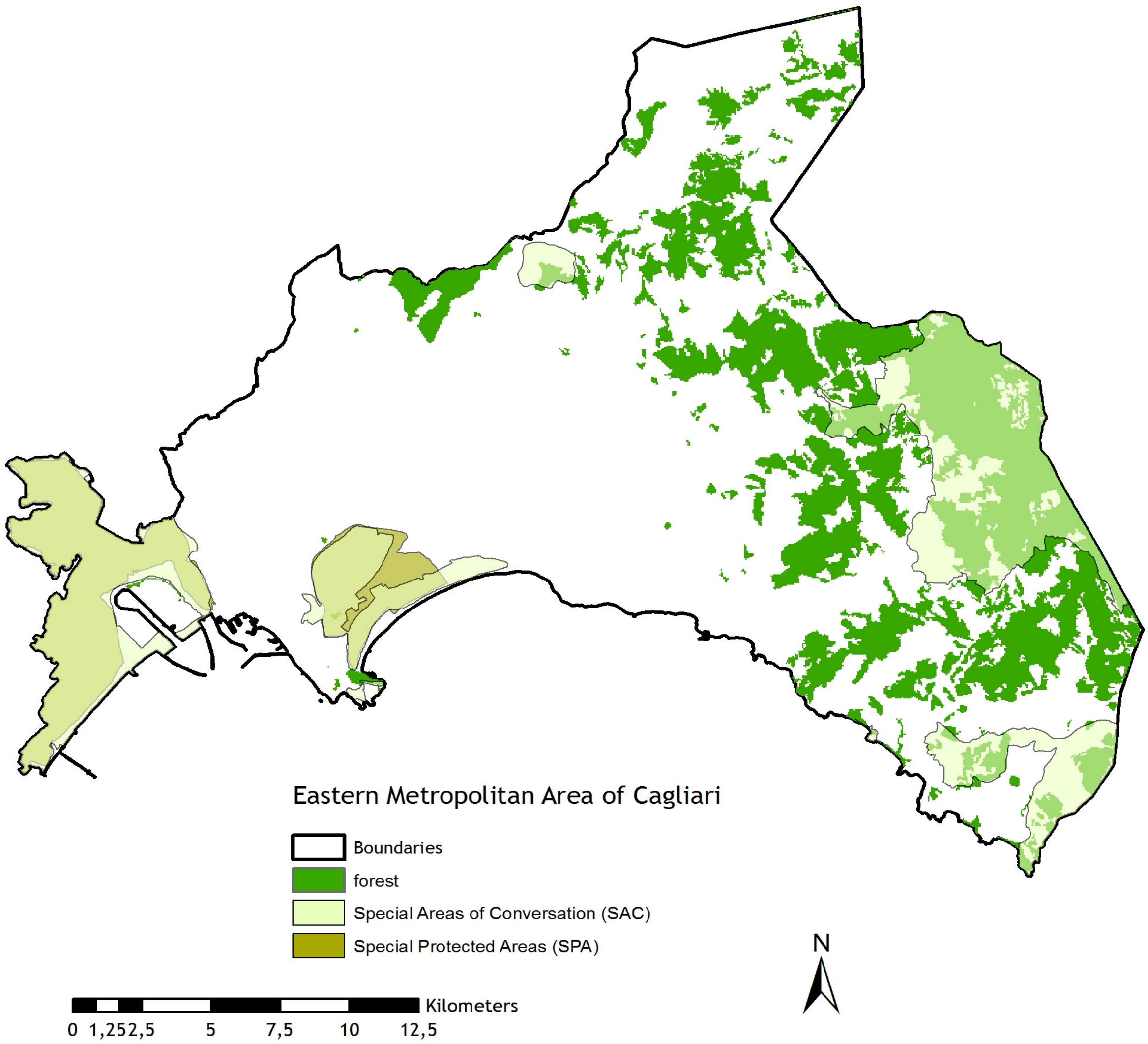


Figure 23: Forests and Natura 2000 sites, scale 1: 250.000

Using Monte Carlo Integration as in formula it was numerically integrated the biomass energy potential according to two criteria: the appearance of afforested areas (V_i) within the radius of 15 kilometres the distance between the potential location of the 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 next to the boundary of the region. The objective is 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). Therefore a grid with a width of 250 m was overlaid over the existing data. Afterwards the area was sampled if afforested areas exist within the defined perimeter. The grid with 250 m was chosen because of the computation time, which was required to perform the process. However 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 around 1 point in 250 [m^2]. After application of the Monte Carlo-integration to existing data the following map resulted as biomass potential map (Figure 24).

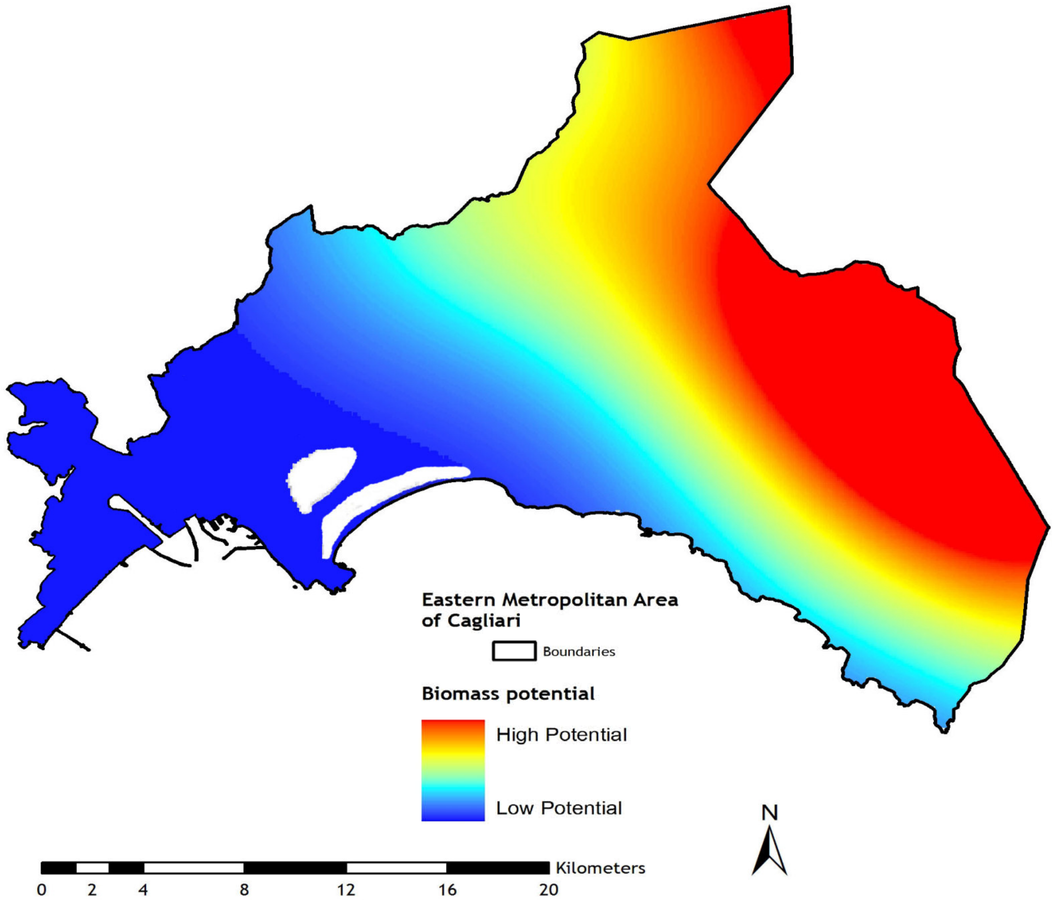


Figure 24: Biomass potential estimation, scale 1: 250.000

In comparison to other potential maps resulting of this study this map is just a qualitative one because forestry considerations were left out. These are for example information about cubic meters of wood per square meter or information about transportation systems and routes. These data could only be considered in more details.

5.7 A multi-criteria framework for energy efficient residential development

To prioritize the importance of each criteria 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 12 shows the weights for each criteria given 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 12: Weights for each criteria for new housing development of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.) from each nationality.

Weights sum to 1. An 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.

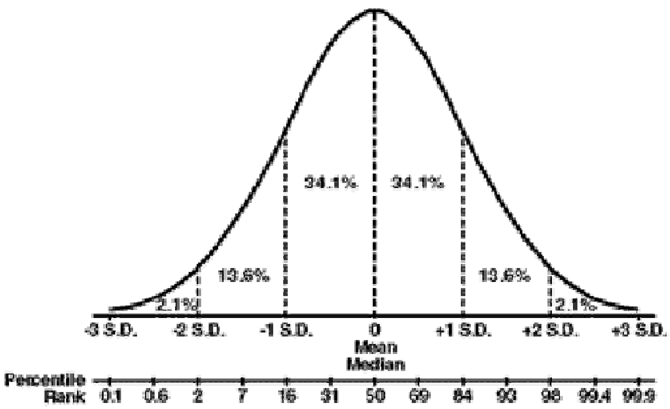


Figure 25: A Normal Distribution(GHAHRAMANI & SAEED 2000: 438).

In a normal distribution:

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

Table 13, 14, 15 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 13, Table 14, Table 15: 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.

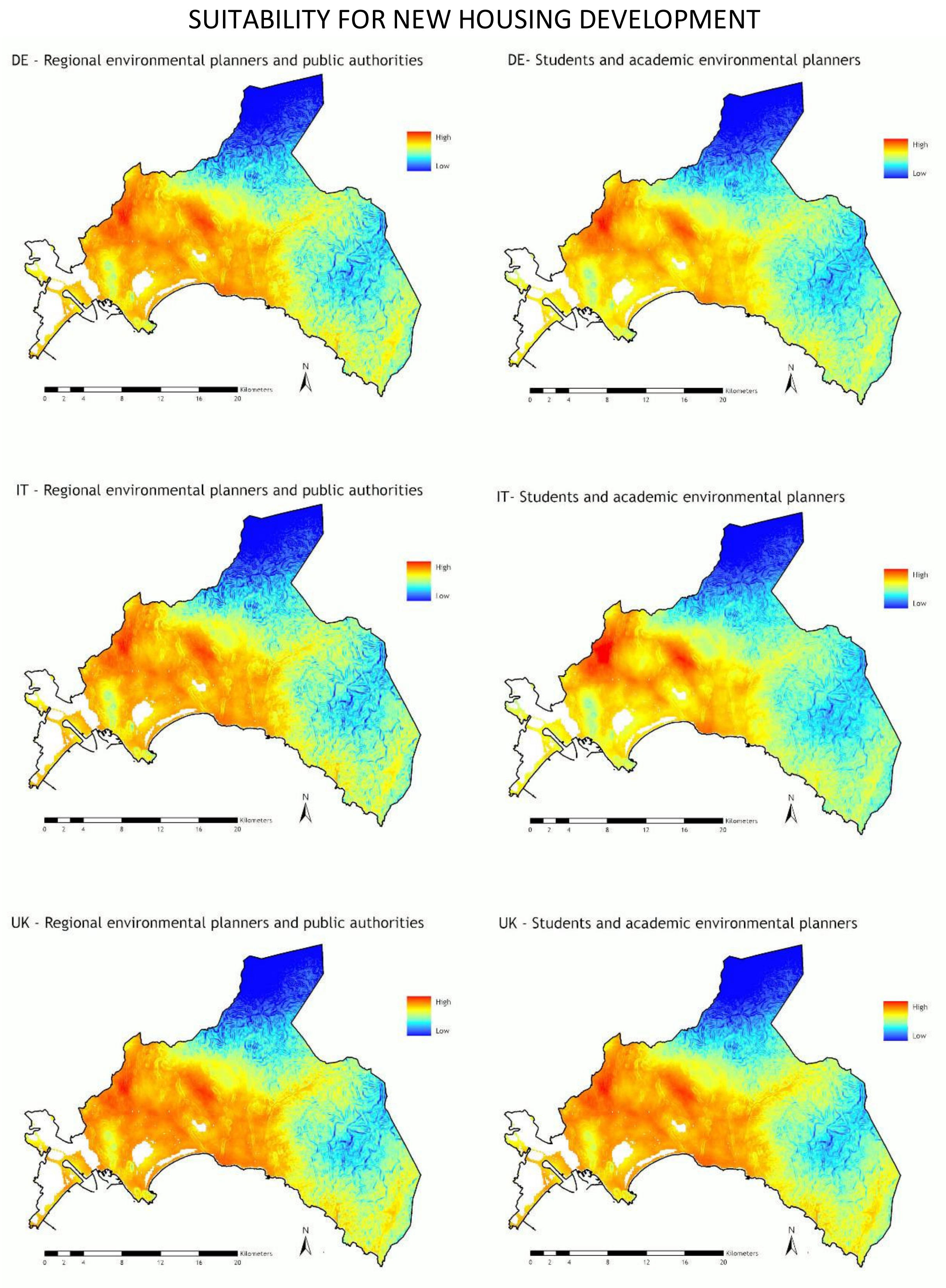


Figure 26: Suitability for new housing development from expert's perspectives.

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

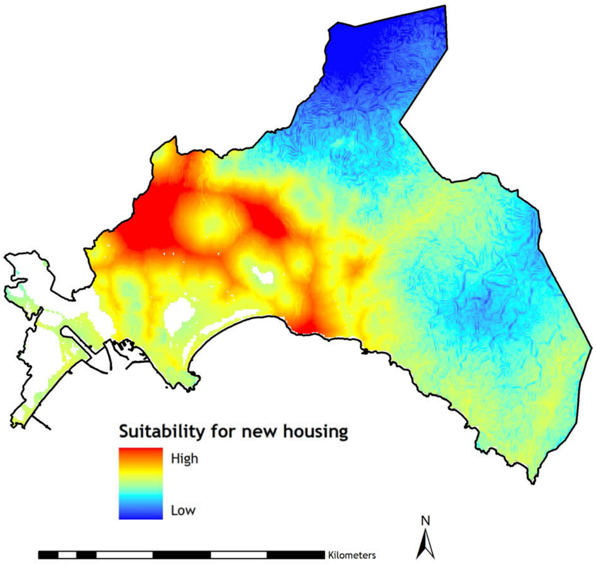


Figure 27 Suitability for new housing-author preference.

(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 an 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 16). 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 16: 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 17-21).

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 17, Table 18, Table 19, Table 20, Table 21: Weights for housing development with micro generation of students and academic planners (S. & AP.) and regional planners and public authorities (RP. & PA.).

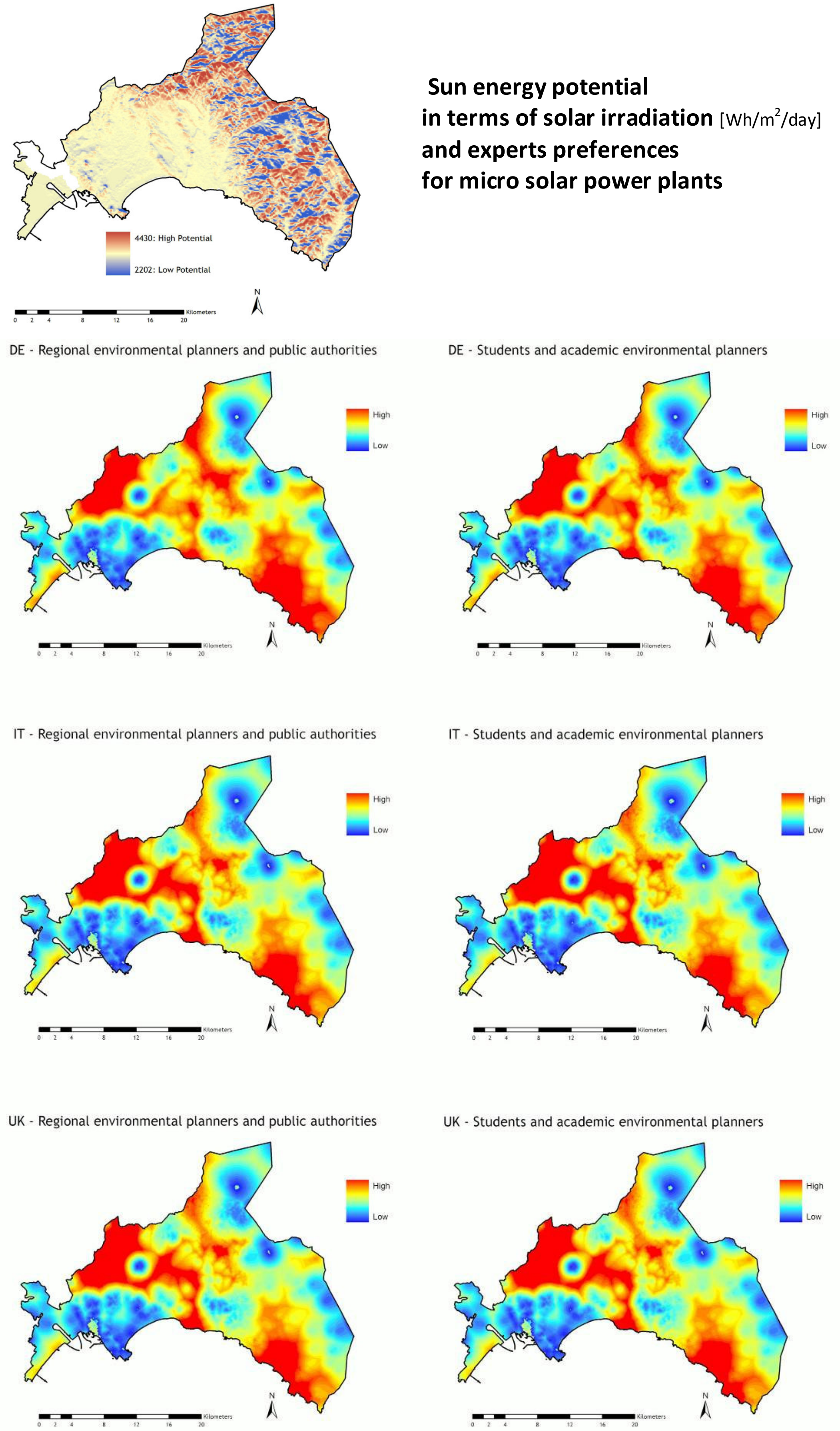


Figure 28 Solar energy potential and suitability for new housing development with micro solar power plants.

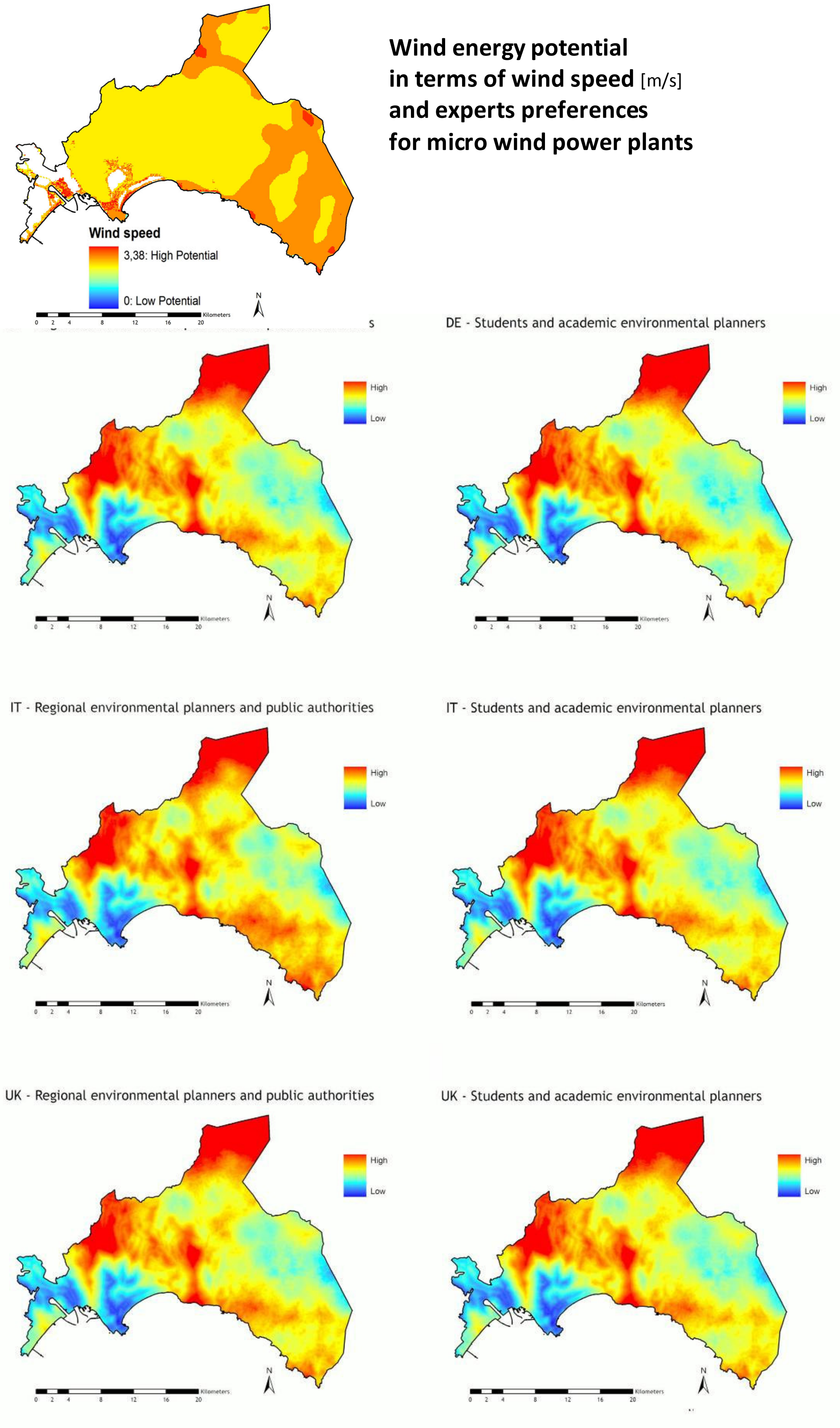
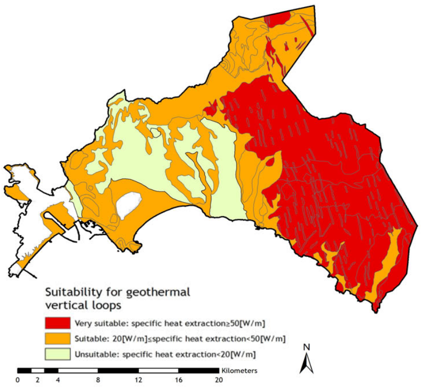


Figure 29 Wind energy potential and suitability for new housing development with micro wind power plants.



Geothermal energy potential
in terms of heat extraction [W/m]
and experts preferences
for geothermal vertical loops

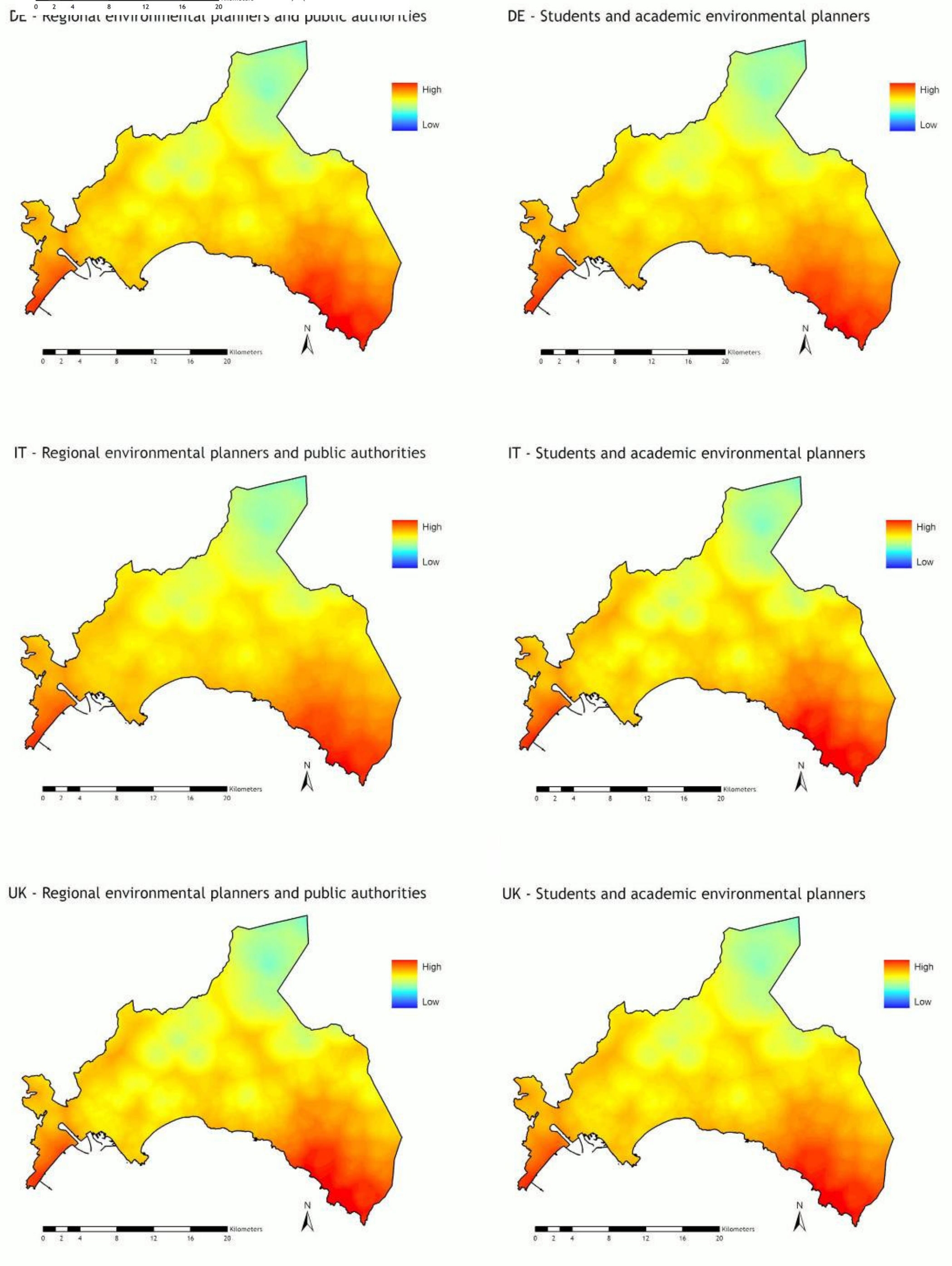
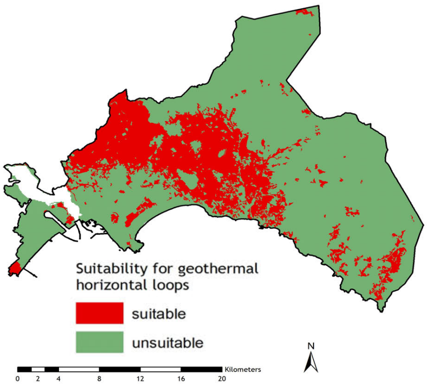


Figure 30 Geothermal energy potential and suitability for new housing development with geothermal vertical loops.

Geothermal energy potential and experts preferences for geothermal horizontal loops



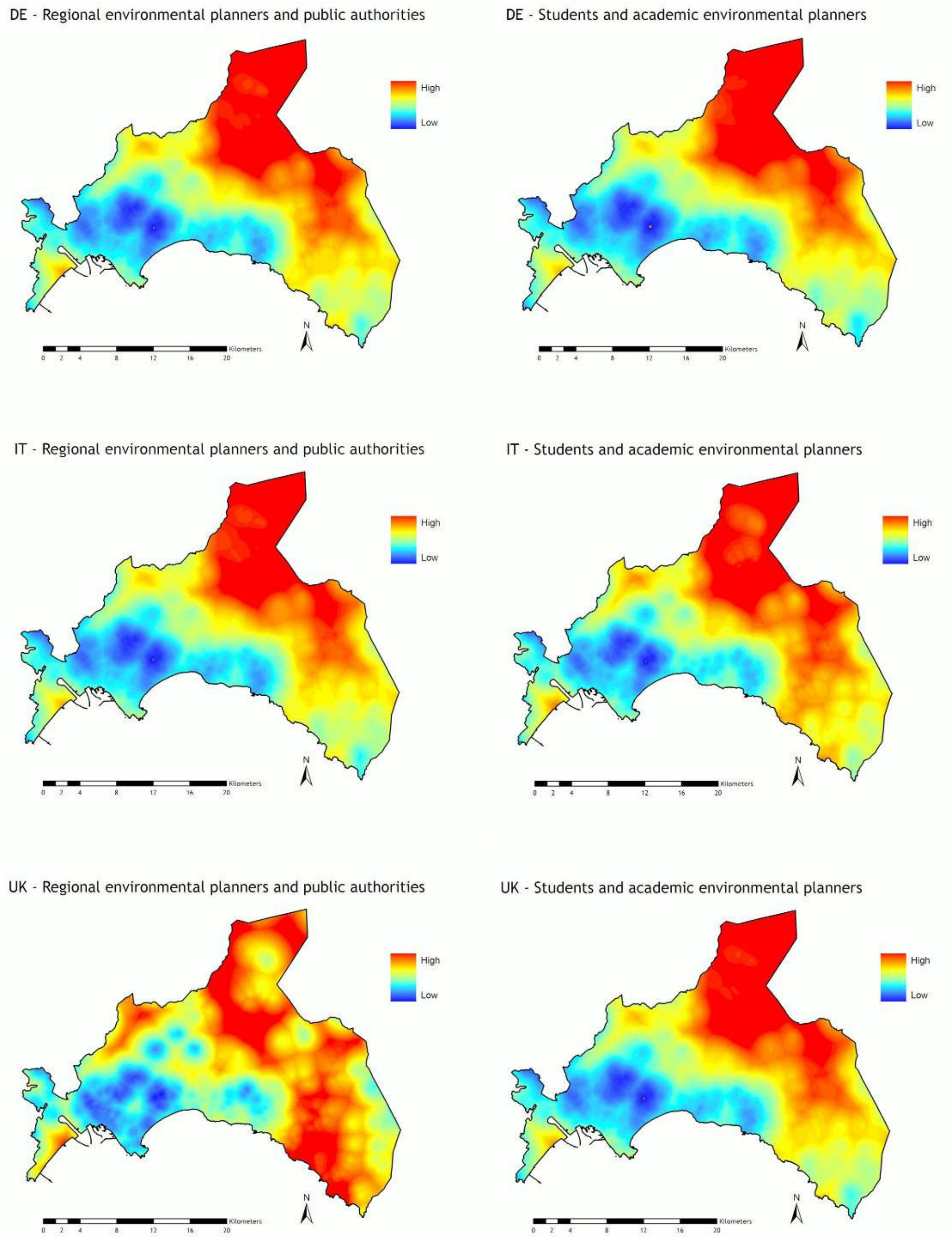
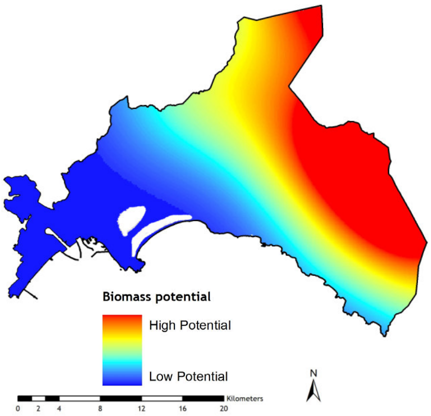


Figure 31 Geothermal energy potential and suitability for new housing development with geothermal horizontal loops.



Biomass energy potential and experts preferences for micro biomass power plants

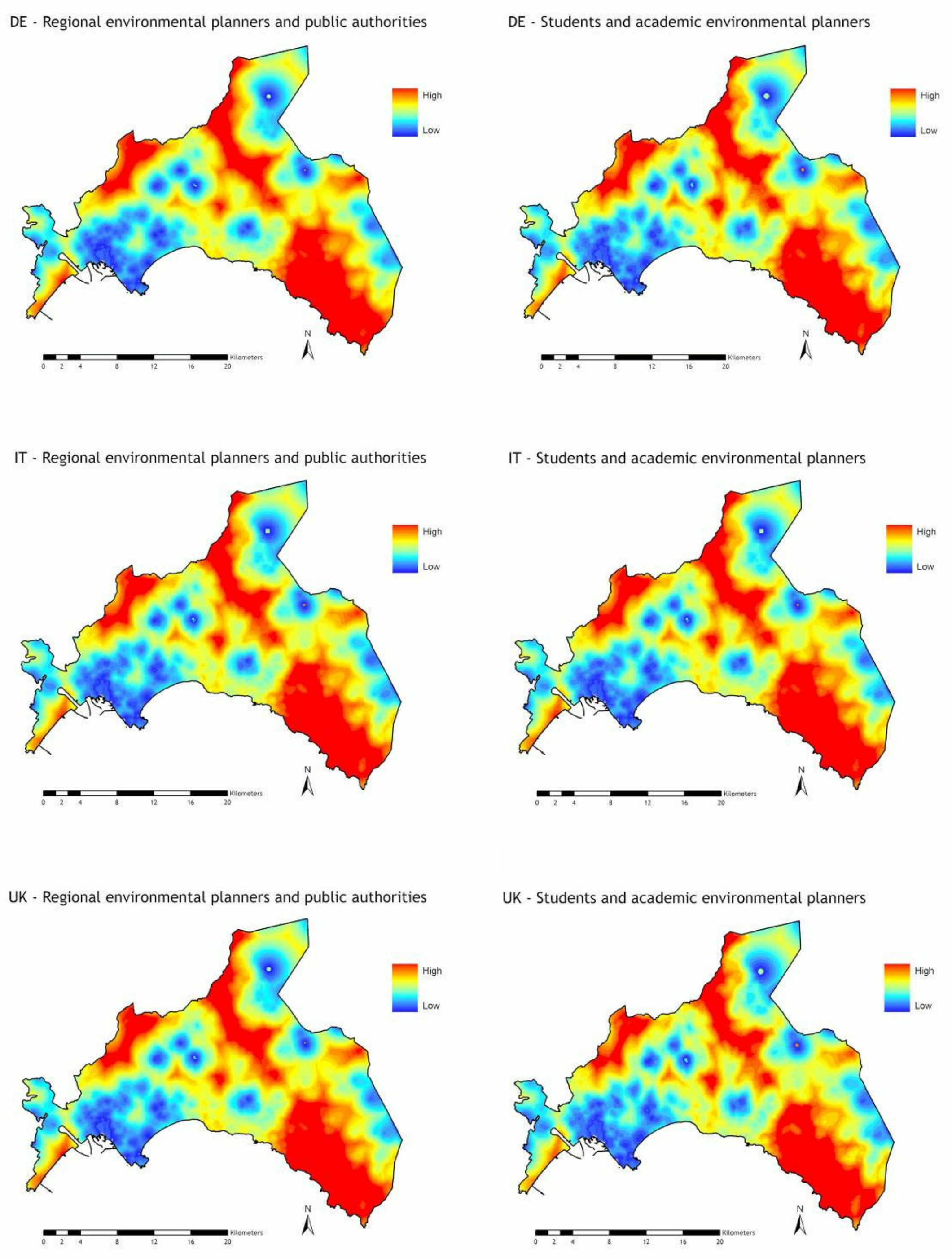


Figure 32 Biomass energy potential and suitability for housing development with micro biomass power plants.

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.

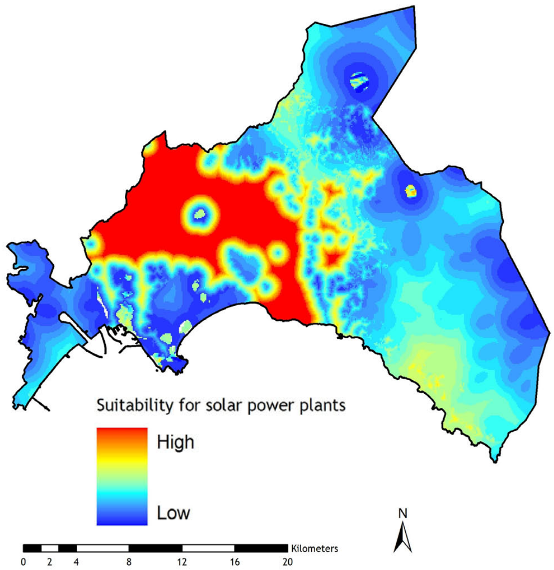
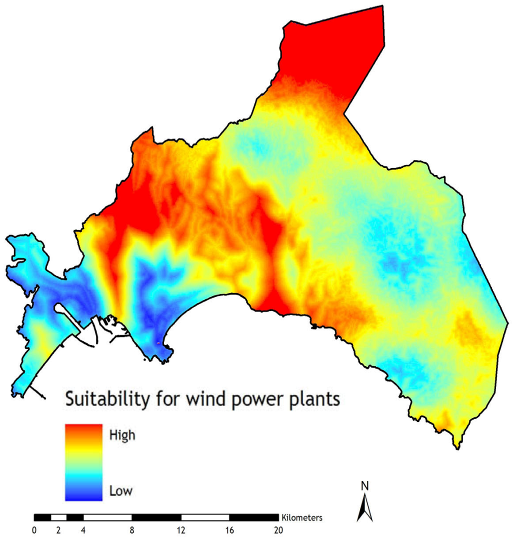


Figure 33 Suitability for micro solar power plant- author preference

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.

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.



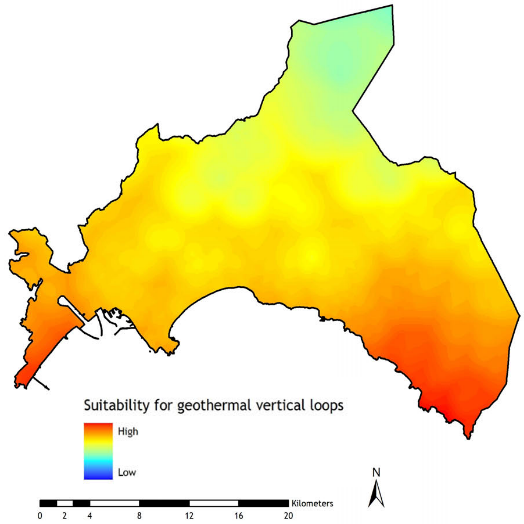


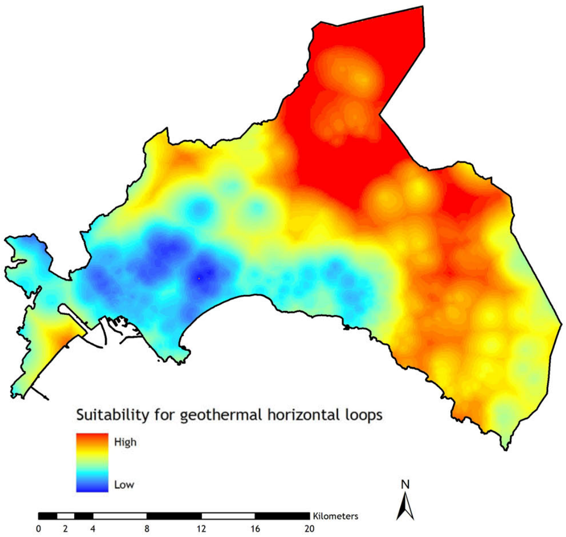
Figure 34, 35 Suitability for micro wind power plants author preference; Suitability for GHL – author preference

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.



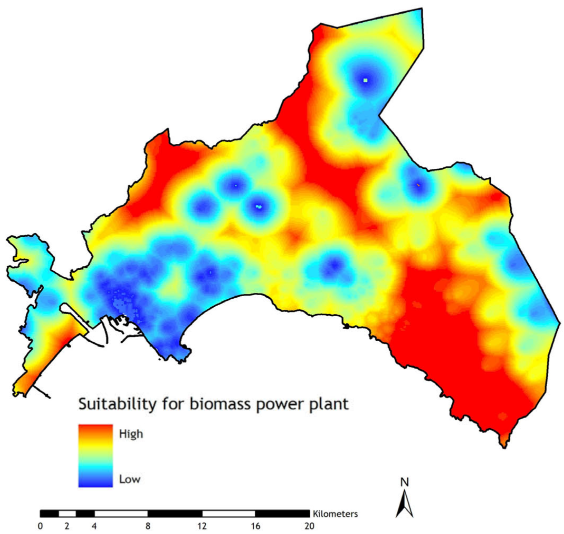


Figure 36 Suitability for GHL – author preference ; **Figure 37:** Suitability for biomass – author preference

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 22 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.22 Average of the SD in % of the mean for all weights of micro generation

Table 22 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 presents the results for each group of criteria of all micro renewable technologies according to the expert preferences (Tables 23-37).

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 23, Table 24, Table 25, Table 26, Table 27: 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 28, Table 29, Table 30, Table 31, Table 32: 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 33, Table 34, Table 35, Table 36, Table 37: 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).

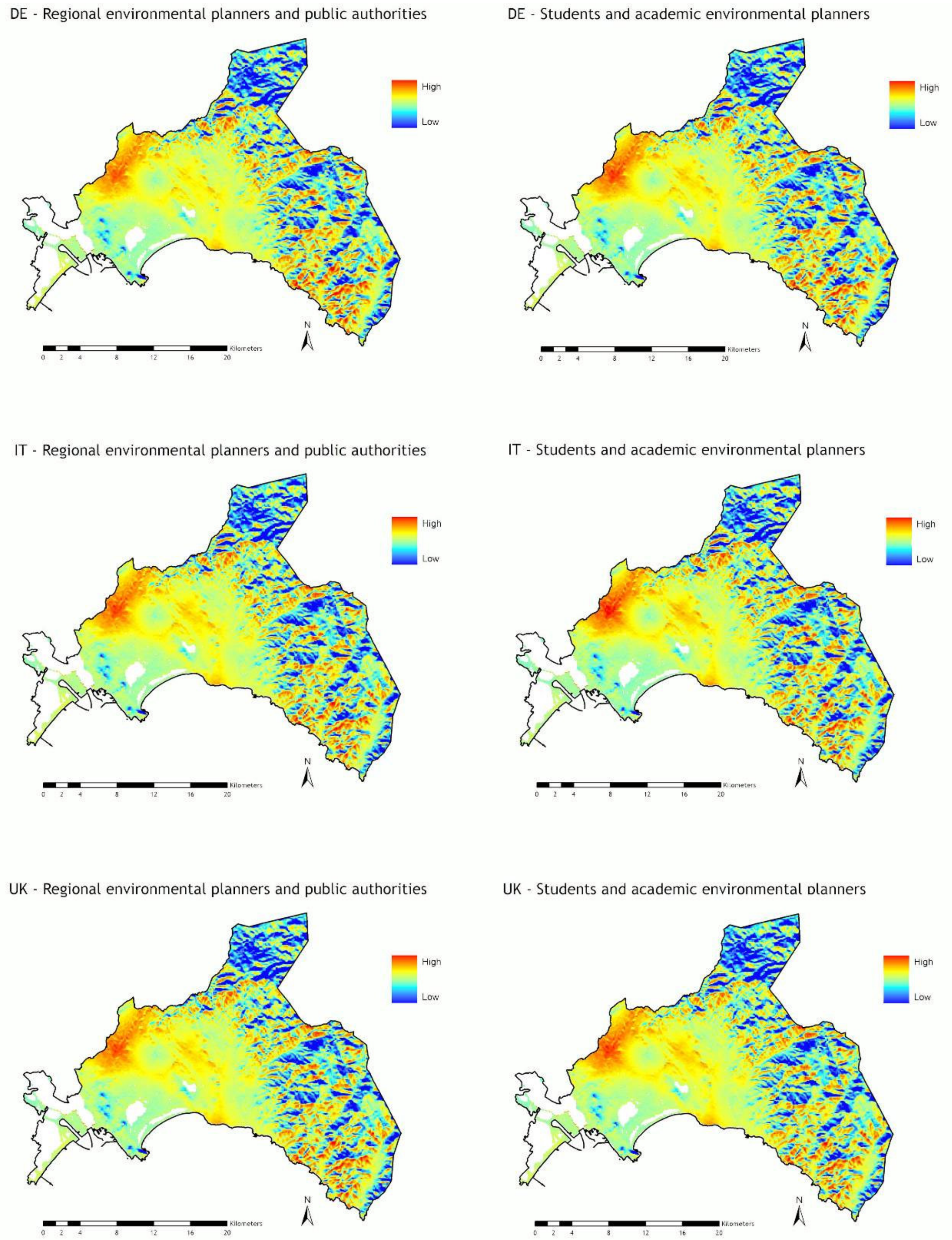


Figure 38: Suitability for housing development with micro solar power plants taking into account the solar energy potential.

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

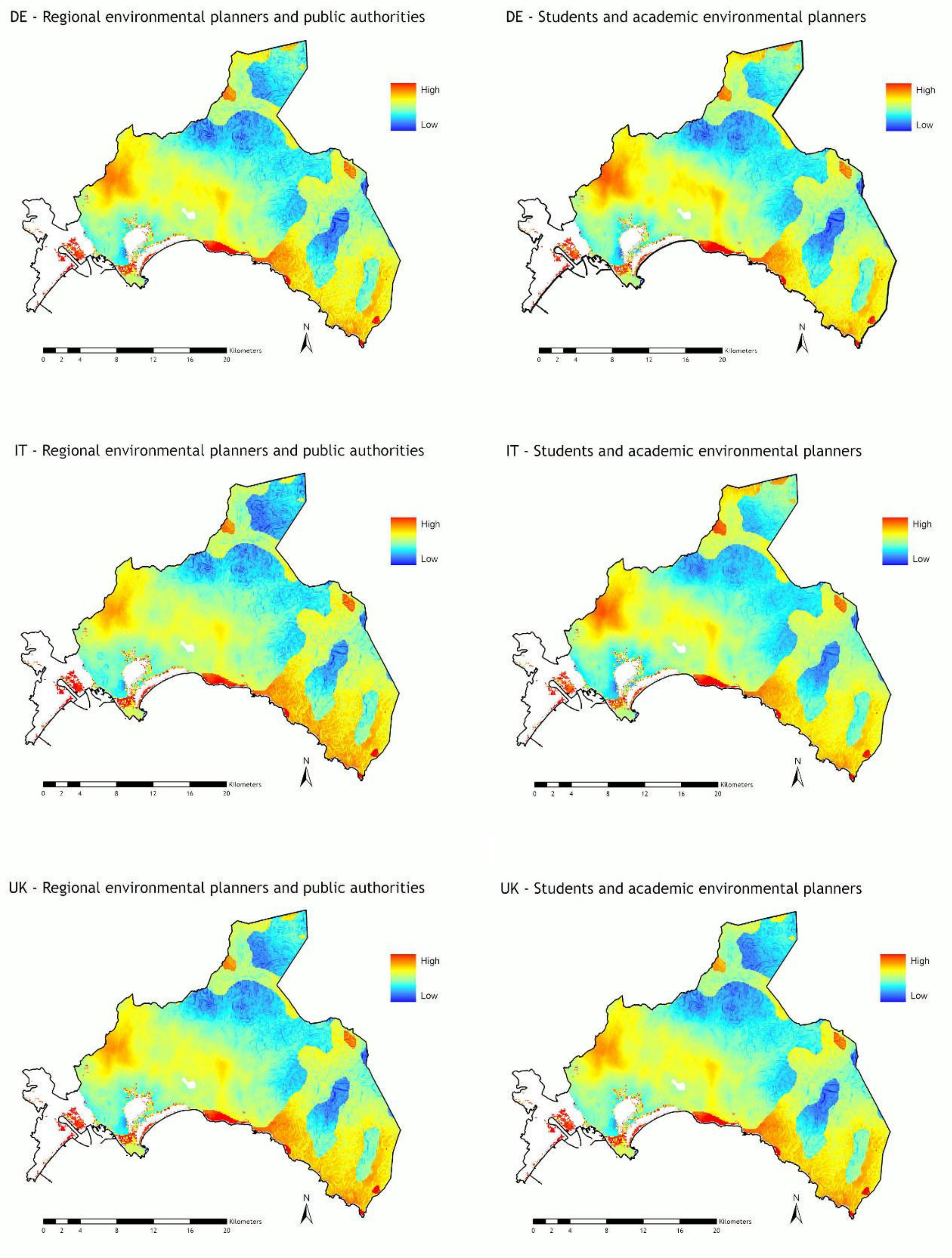


Figure 39: Suitability for housing development with micro wind power plants
taking into account the wind energy potential.

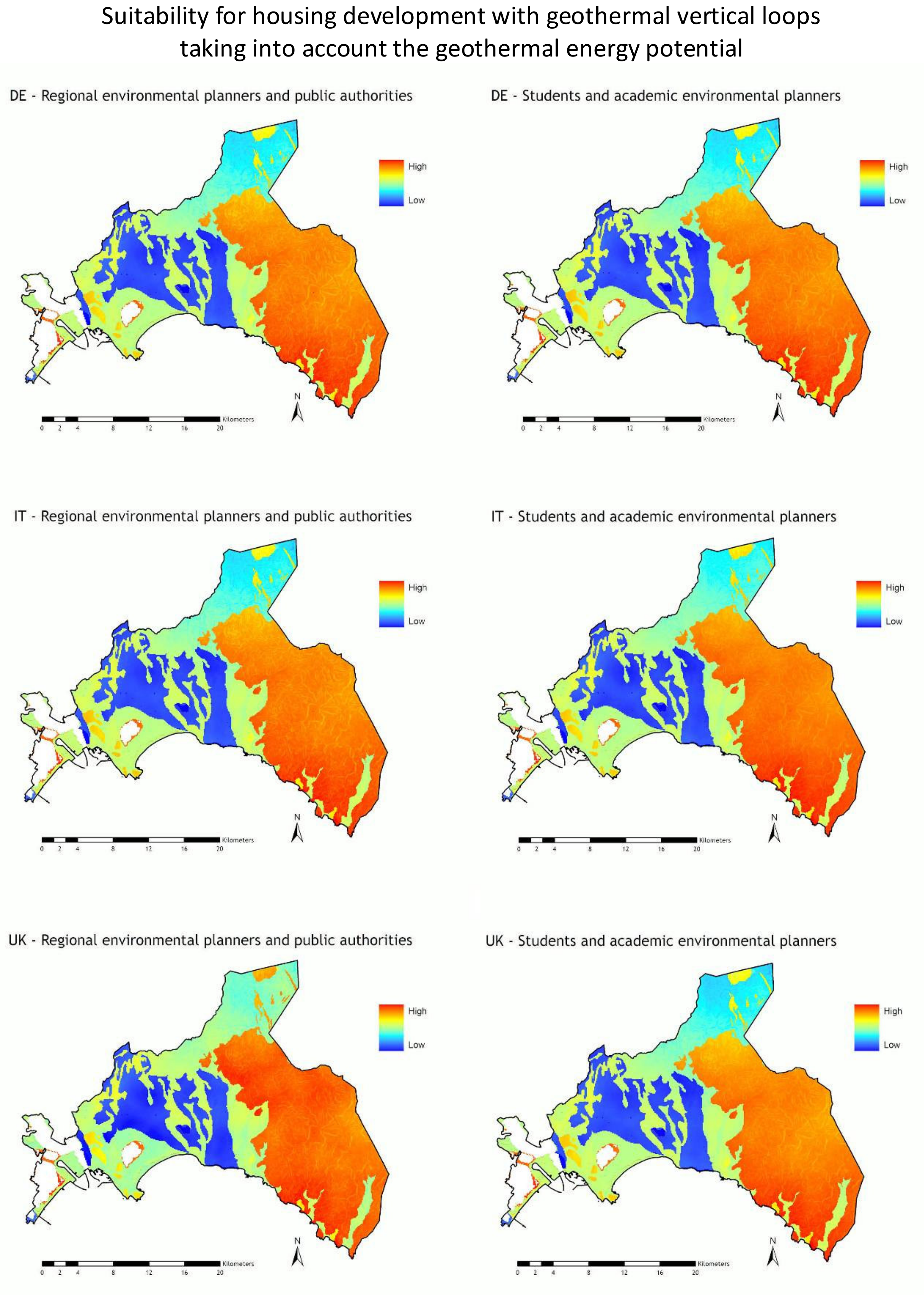


Figure 40: Suitability for housing development with geothermal vertical loops taking into account the geothermal energy potential.

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

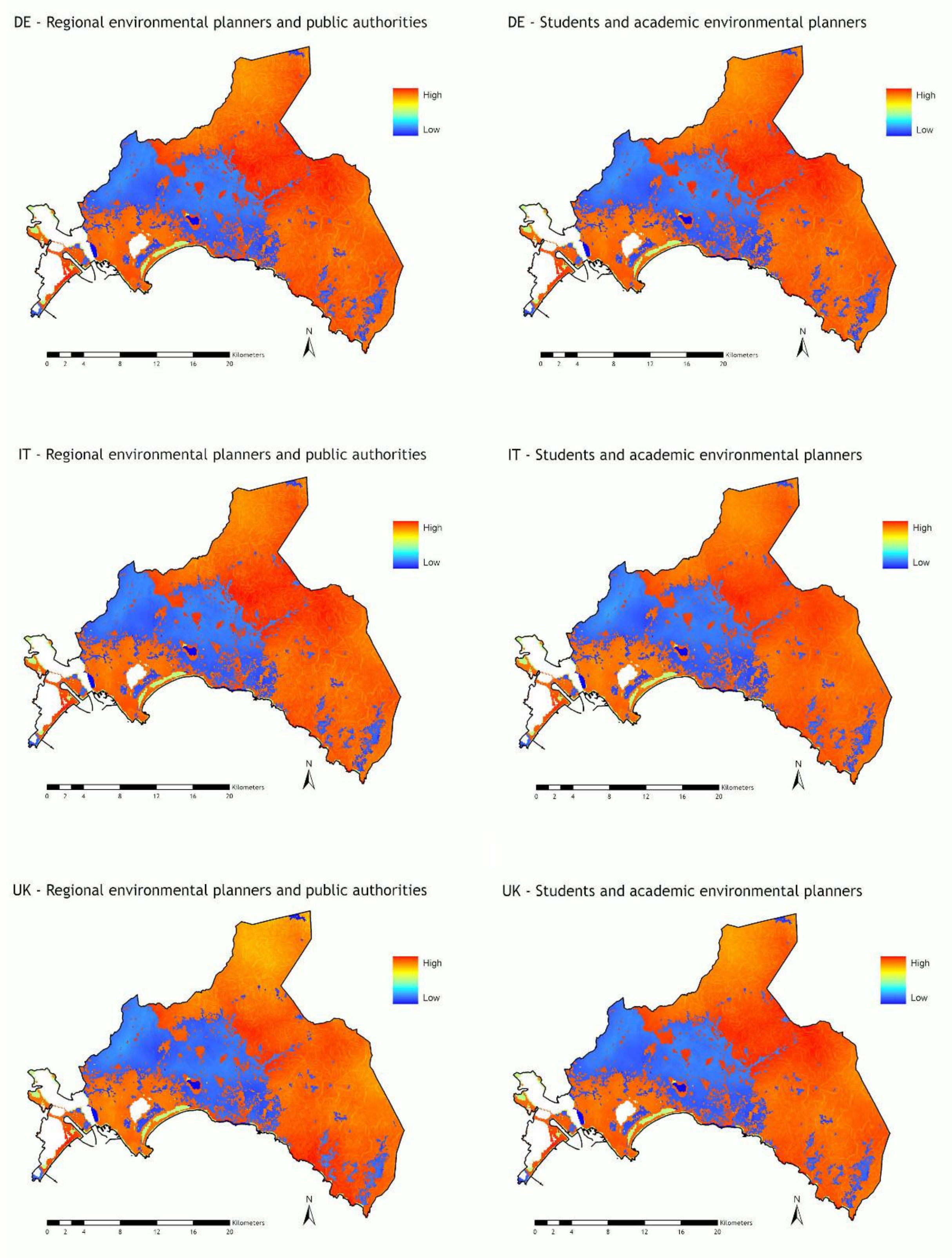


Figure 41: Suitability for housing development with geothermal horizontal loops taking into account the geothermal energy potential.

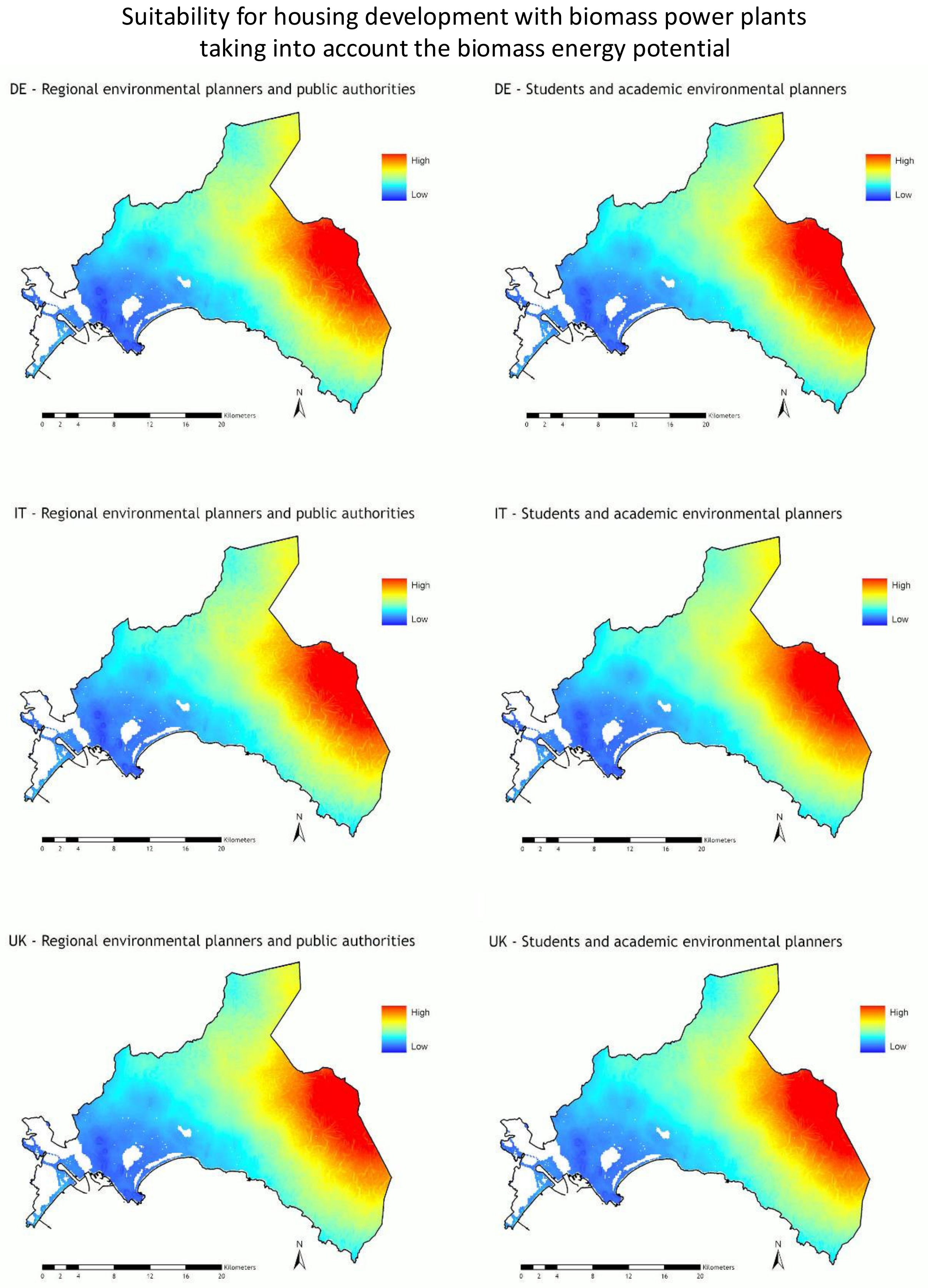


Figure 42: Suitability for housing development with biomass power plants taking into account the biomass energy potential.

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).

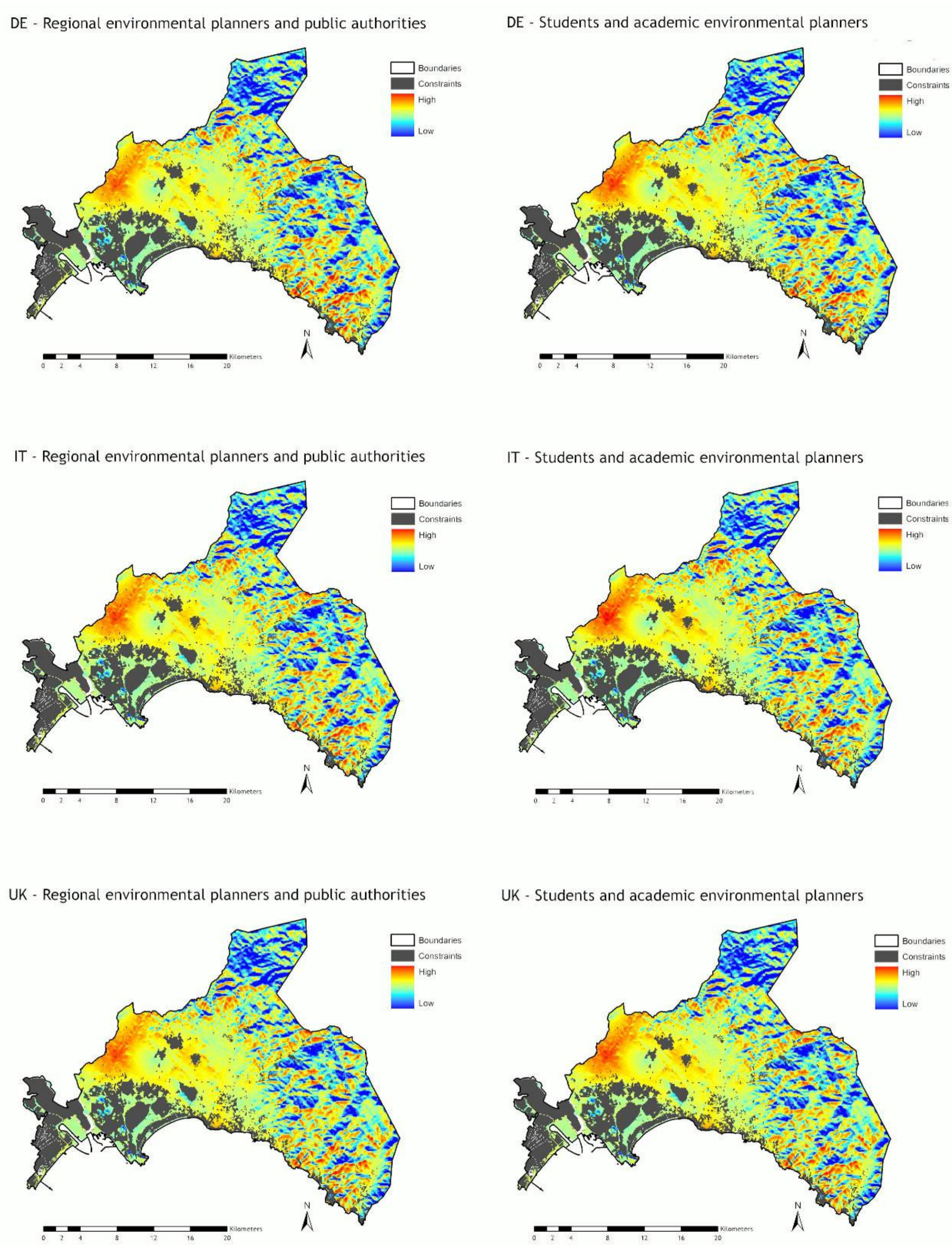


Figure 43: Suitability for housing development with micro solar power plants taking into account the solar energy potential and the constraints.

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

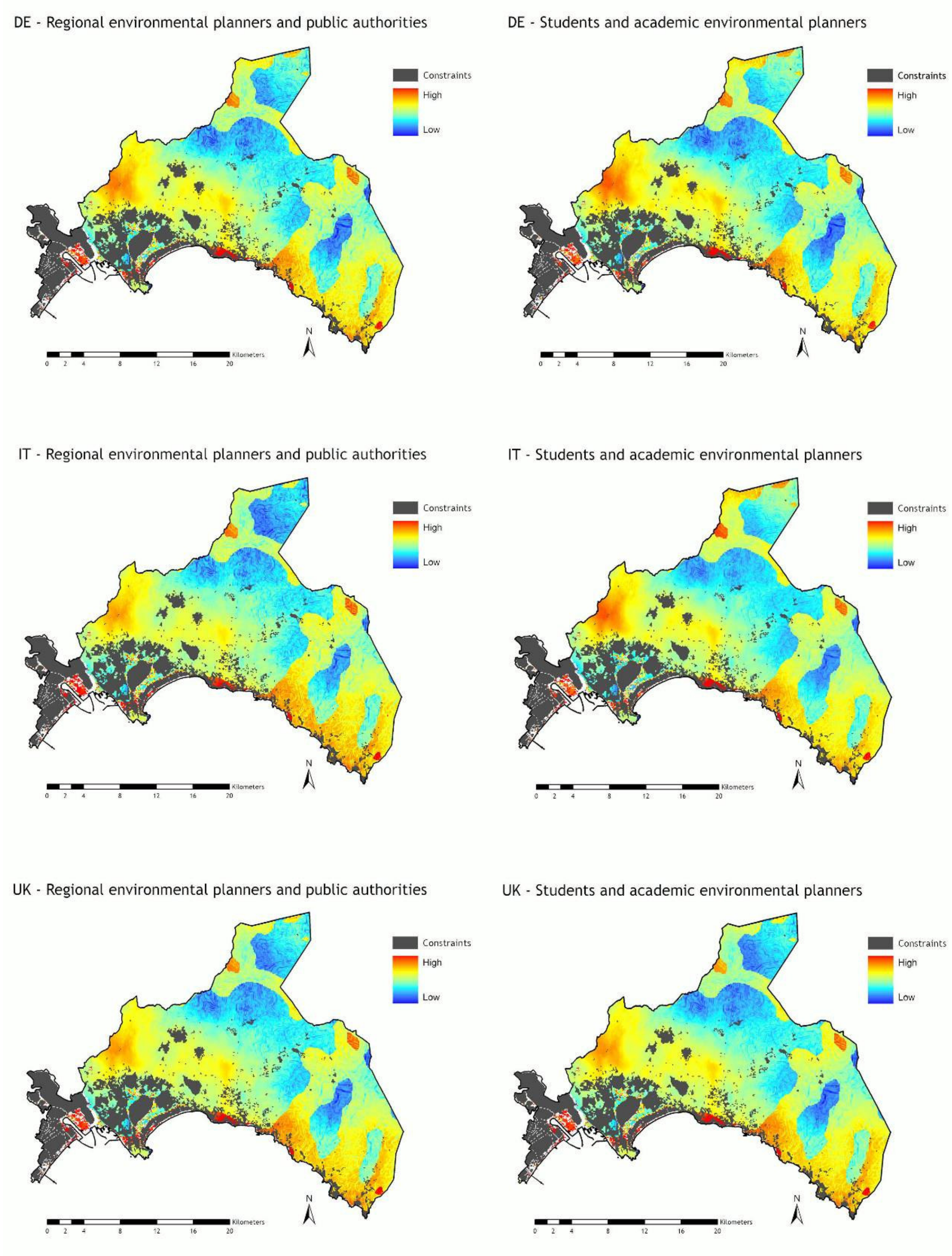


Figure 44: Suitability for housing development with micro wind power plants
taking into account the wind energy potential and the constraints.

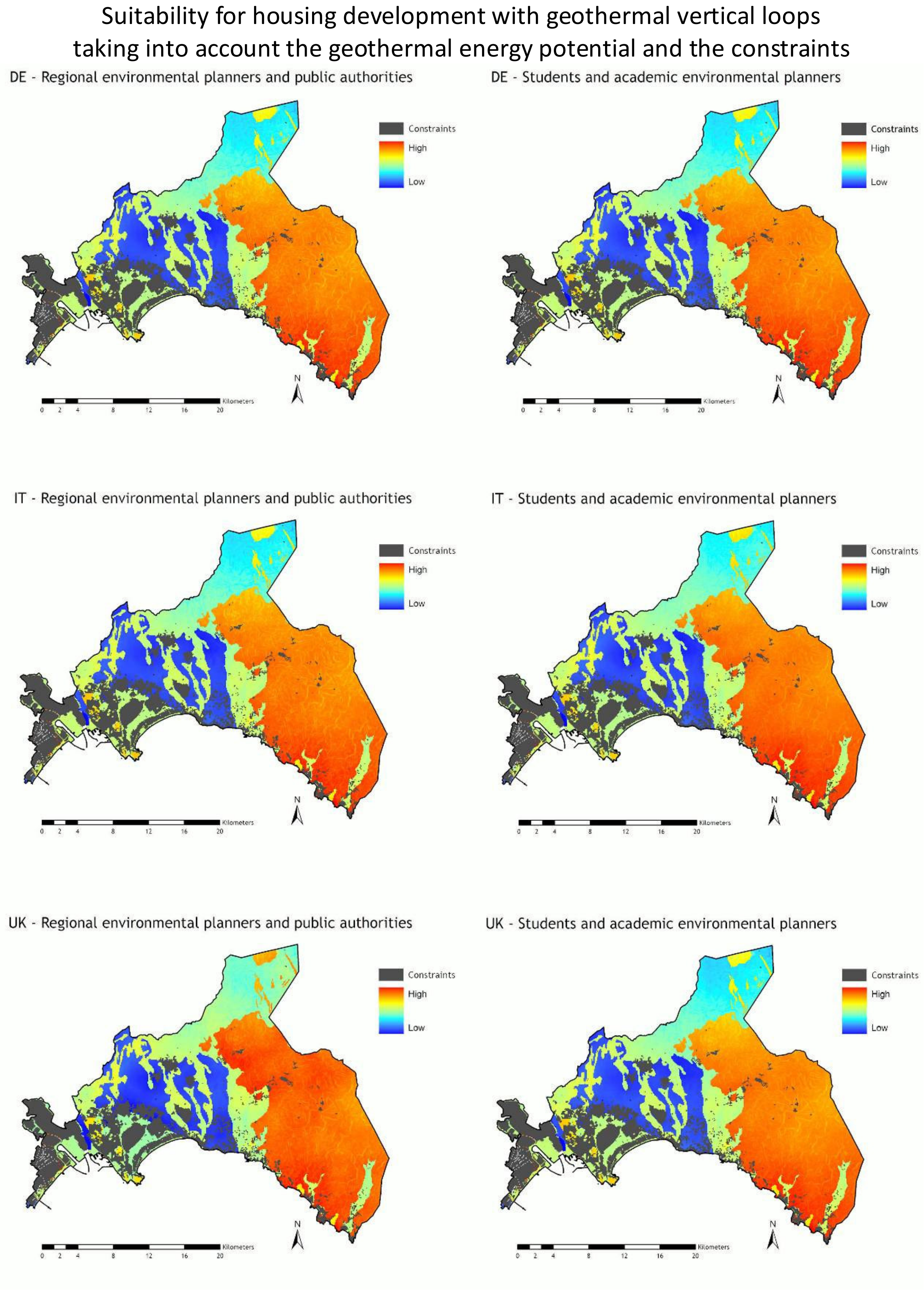


Figure 45: Suitability for housing development with geothermal vertical loops taking into account the geothermal energy potential and the constraints.

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

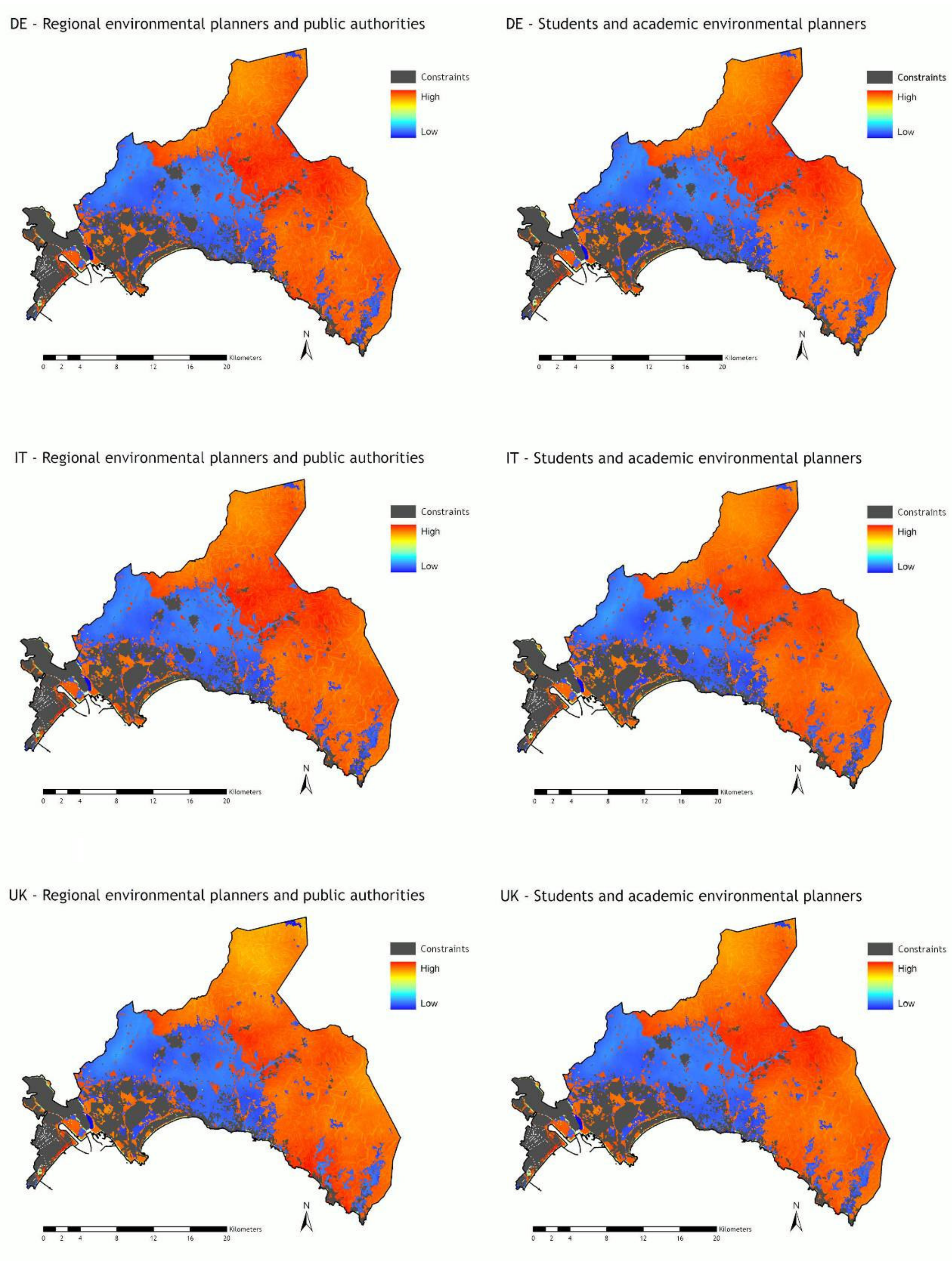


Figure 46: Suitability for housing development with geothermal horizontal loops taking into account the geothermal energy potential and the constraints.

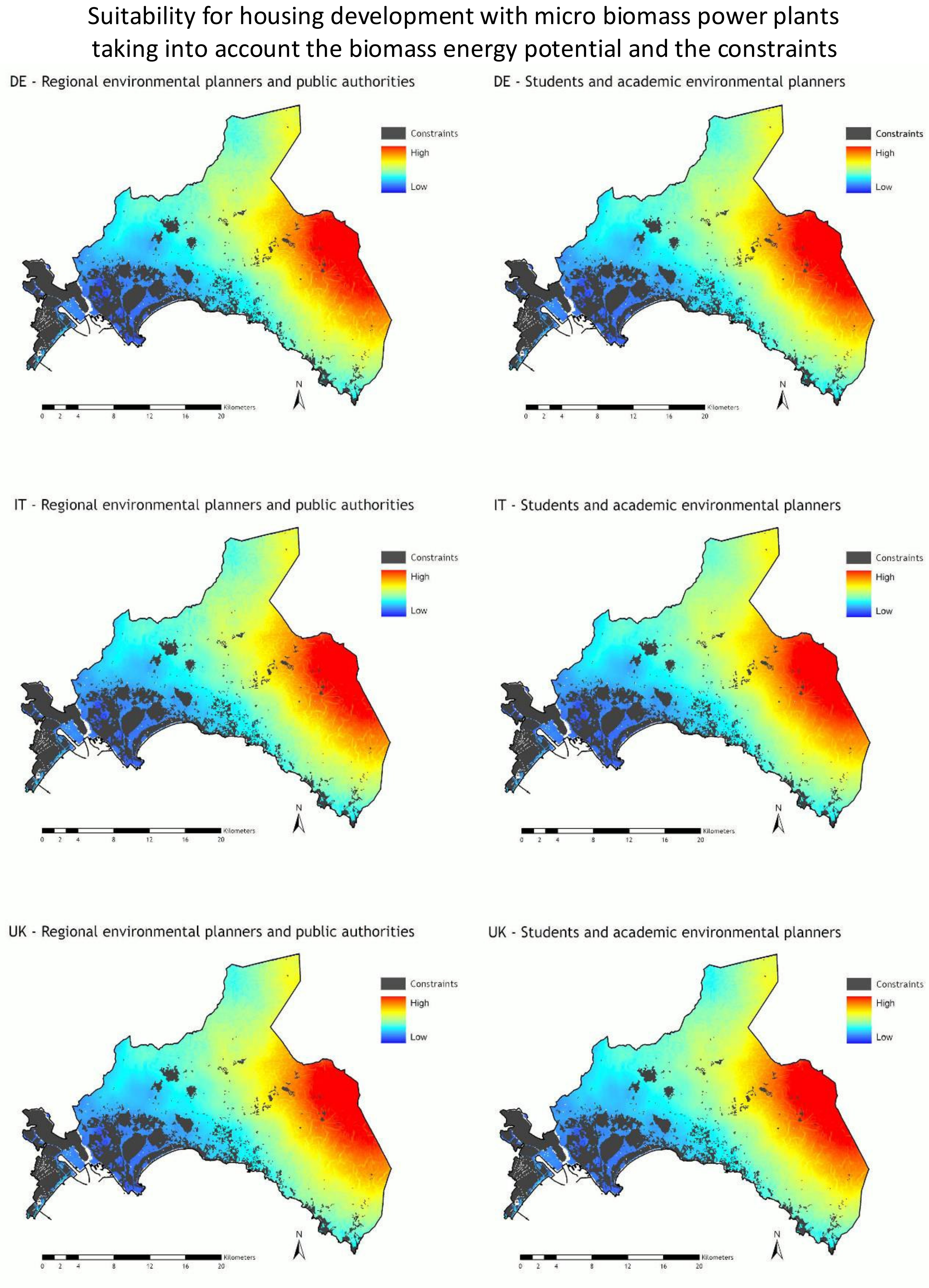


Figure 47: Suitability for housing development with micro biomass power plants taking into account the biomass energy potential and the constraints.

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 an 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 are already existing.

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:

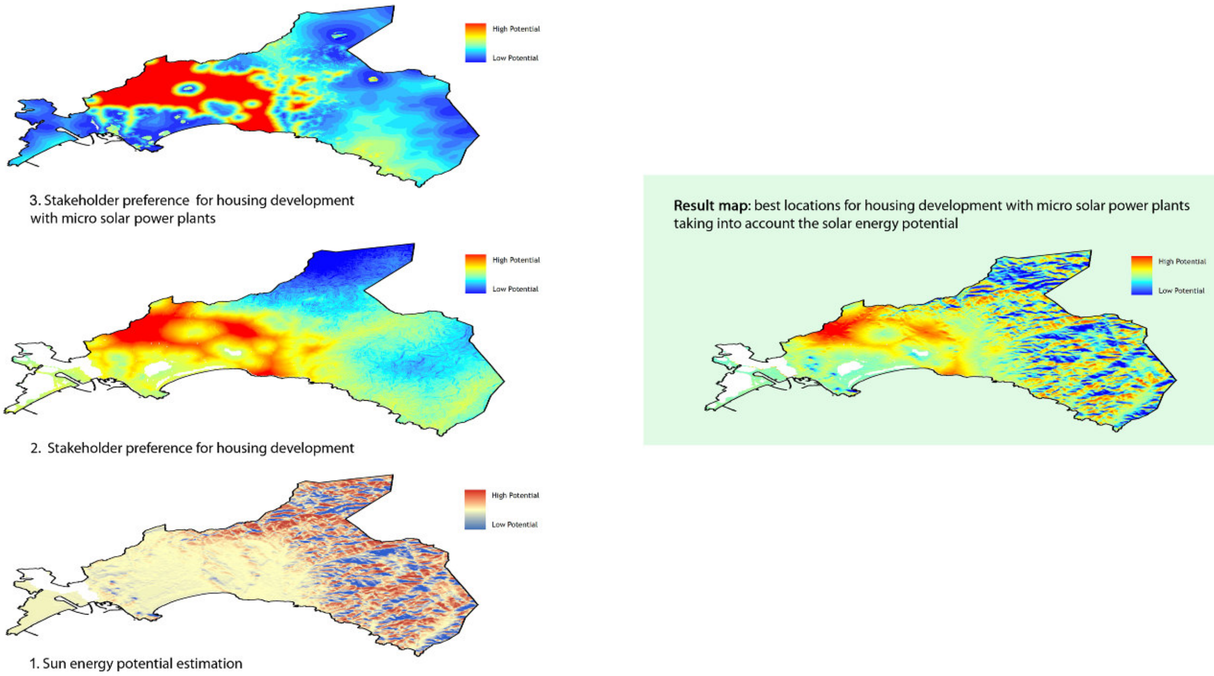


Figure 48: Overlaying layers to obtain the suitability map for housing development with micro solar power plants.

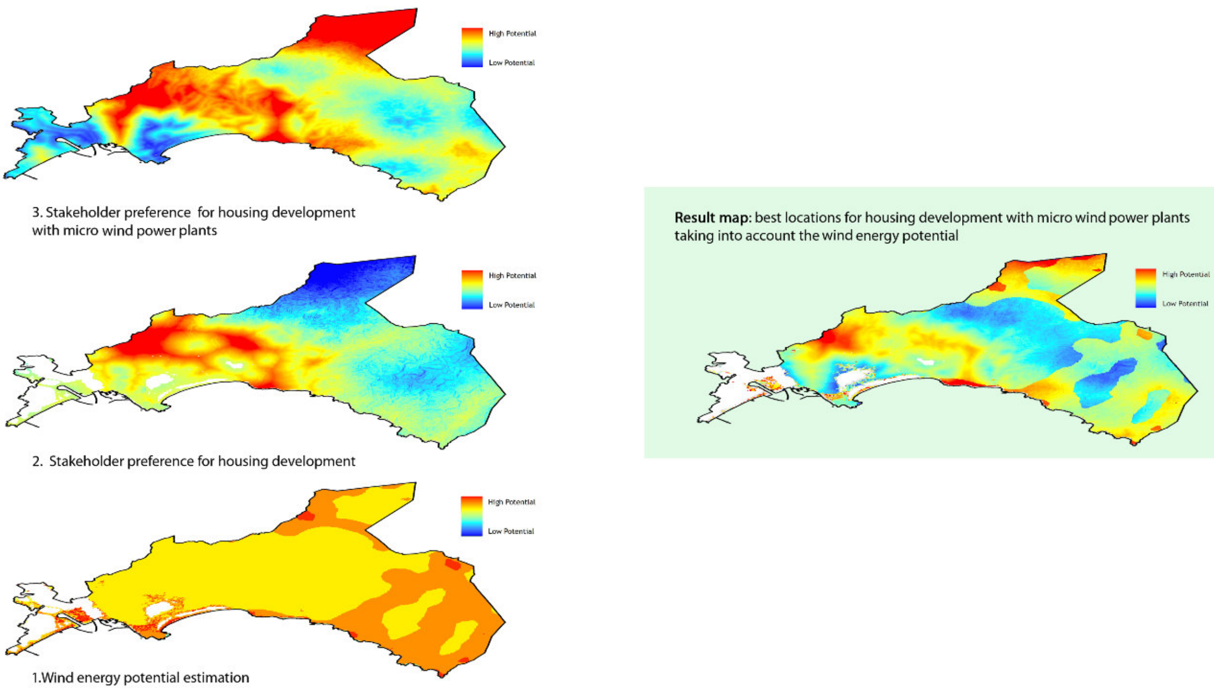


Figure 49: Overlaying layers to obtain the suitability map for housing development with micro wind power plants.

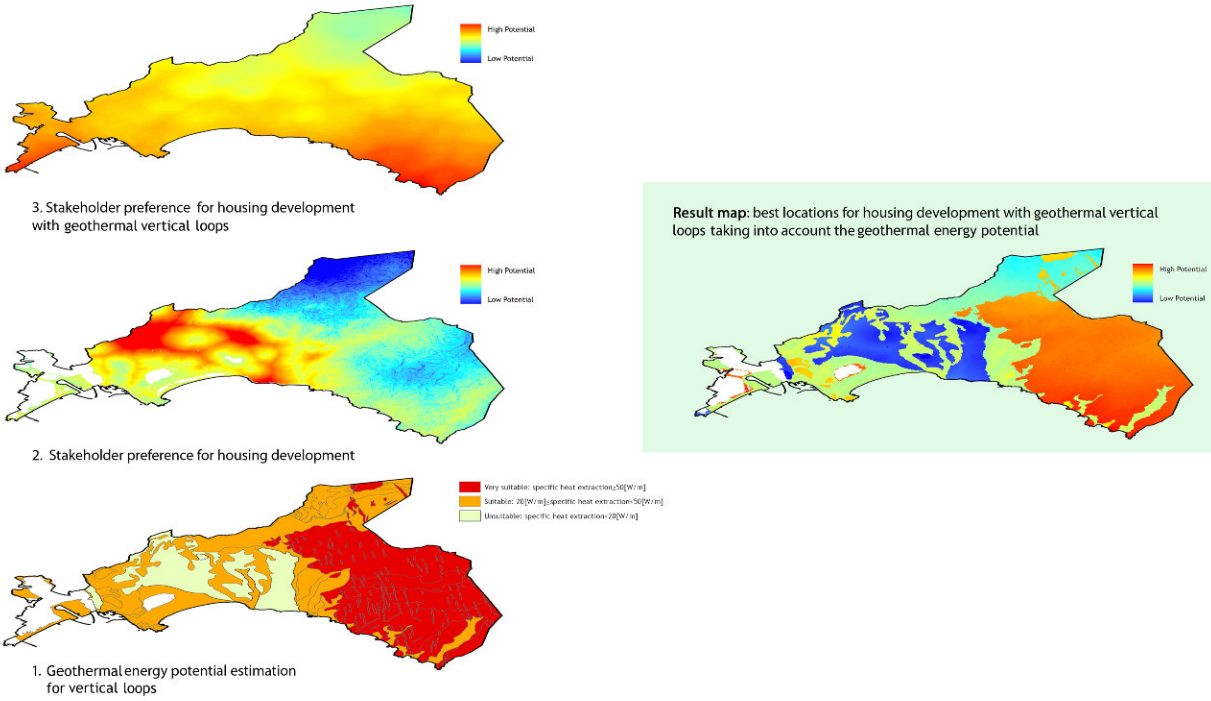


Figure 50 Overlaying layers to obtain the suitability map for housing development with geothermal vertical loops.

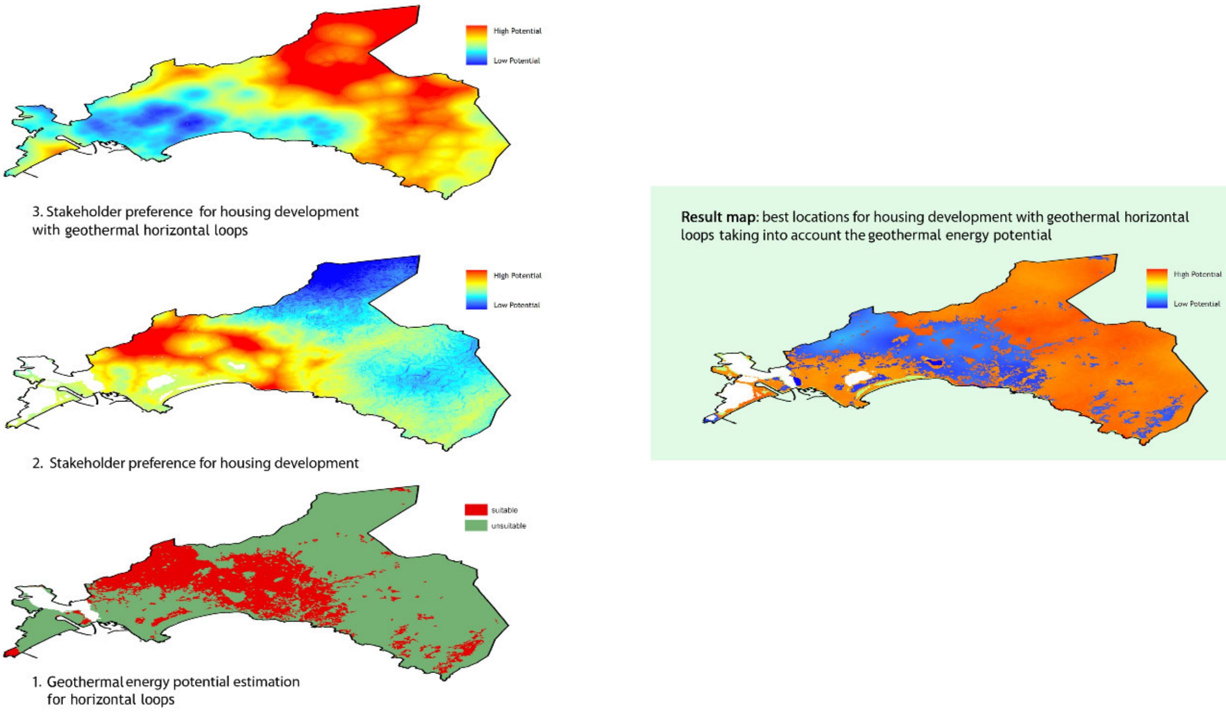


Figure 51: Overlaying layers to obtain the suitability map for housing development with geothermal horizontal loops.

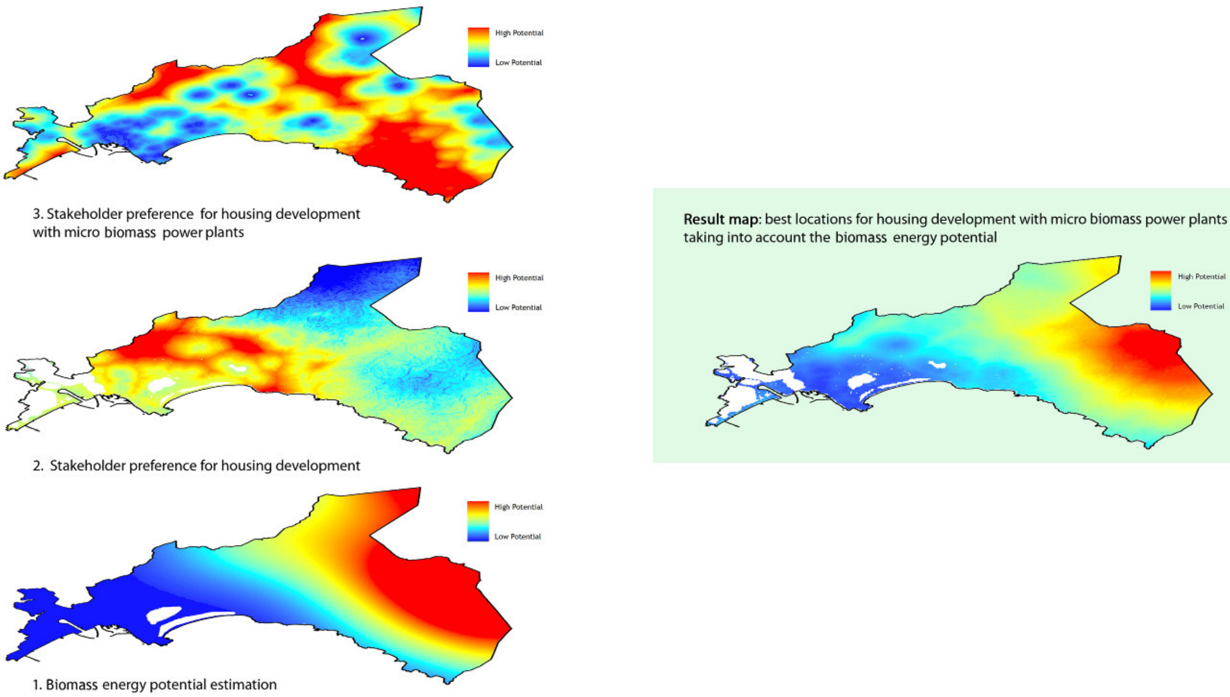


Figure 52: Overlaying layers to obtain the suitability map for housing development with micro biomass power plants.

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 38). 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 38: 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.39). 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 39: 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 (Tab.40). 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 40: 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 41, 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 41: Expert preferences about the integration of micro technologies for heat and electricity production

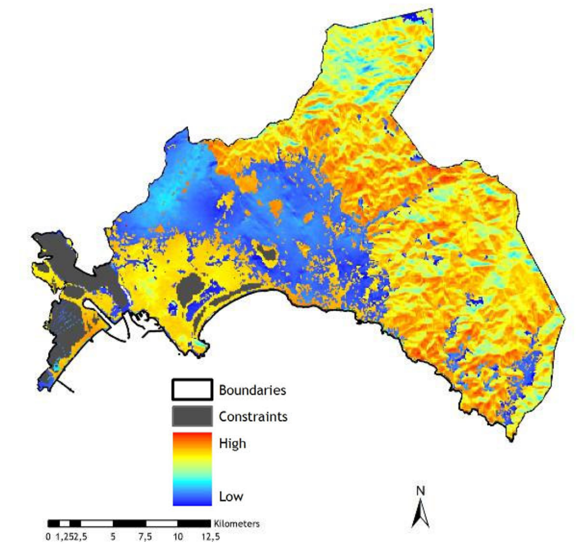


Figure 53

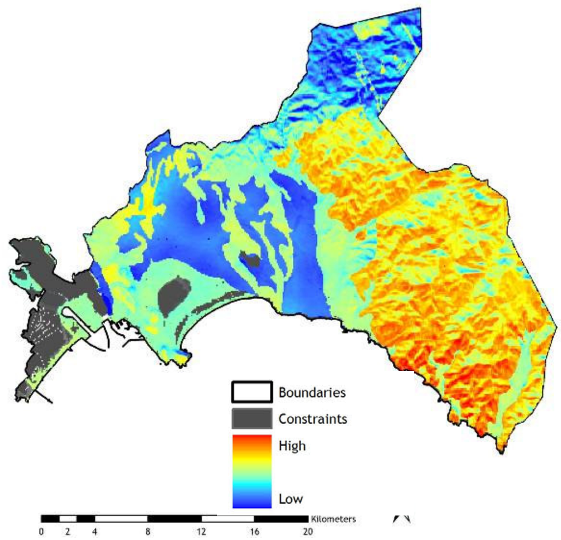


Figure 54

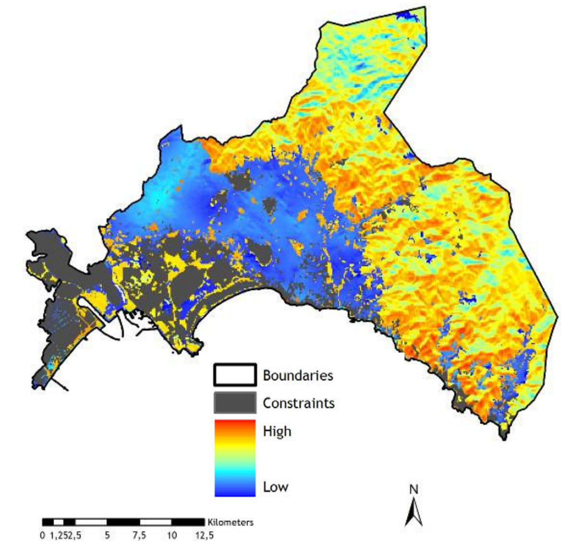


Figure 55

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)

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.

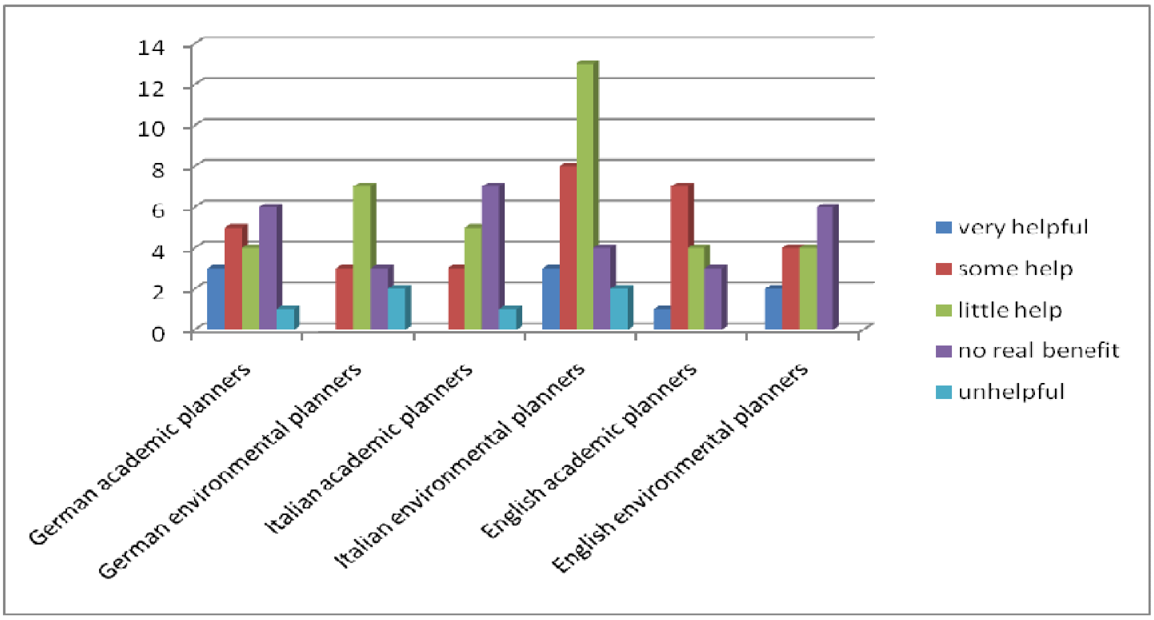


Figure 56: Experts opinions about the integration of visualization in the questionnaire.

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 need to reduce oil consumption and to produce renewable energy favours the integration of micro renewable energy generation into housing development. The integration in the urban and regional planning of alternative power generating sources can play a key part in reducing the region's dependence on external fuels. Micro generation technologies (wind, solar, biomass and geothermal) provide a significant source of renewable and environmentally clean energy by developing 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 as well as by choosing the best mix of renewables for each individual residential site. This thesis suggested a method for finding the best locations for new housing developments which use micro renewable technologies. Decisions about the best energy mix for the different residential areas can be supported by the results. The proposed approach was based on assessment of the energy potential and an assessment of other relevant criteria which have been weighted by expert preferences.

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

The calculation of the solar energy potential estimation depends on the application of *r.sun* model and on the *pvgis* data, therefore it can be applied in every regions. However, the accuracy depends on input data (DEM) and on *pvgis* or other measured data availability. Furthermore, the *r.sun* model can also estimate the 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 estimated at bigger scale for a 3D city model.

Data of wind speeds are also available in every country. The only difference between the German and the Italian wind speeds was that the German one were calculated at 10 m height, while the Italian one at 25 m height. Wind speeds give a good approximation about the wind energy potential, but for the planning of new settlements simulation of the wind flow can be useful in this context.

The accuracy of geothermal energy estimation was dependent on data availability (e.g. profiles) about the rocks layers under the ground for geothermal vertical loops and about the ground up to 1.3 m for geothermal horizontal loops. The study demonstrated that even if no sufficient data on stratification and soil characteristics already exist, the information needed can be generated by the assistance of geologists with local knowledge. Nevertheless, it should be aimed at producing suitability maps for the use of horizontal loops for a wide spread use of geothermal micro generation. For more precision it will be necessary to conduct further specific studies on site and local analysis, required for the planning and design of horizontal loops. For instance, the Region of Sardinia has recently developed a geological map, scale 1:20.000, which can be helpful for further research to obtain a more accurate geothermal energy potential estimation.

It will be also important to have more detailed data about the groundwater level and movement to estimate the geothermal energy potential using the groundwater flow. Even though no detailed map of the geothermal resources of this area was currently available, it is reasonable to assume that the area has a good geothermal potential due to the presence of subsoil aquifers and vast lagoons (RANIERI & PIRODDI 2009). One of the features that already make low enthalpy geothermal research extremely promising is the possibility of complementing geothermal applications with other renewable energy sources, both from a functional system view point and from an architectural perspective. Geothermal systems are particularly suited for this, as they do not require any particular environmental condition. Furthermore, we need to consider that exploiting geothermal resources goes in the direction of fundamental independence from fossil fuels, thus offering the potential for autonomous decisions on energy policies and for moving towards economically competitive technologies, as traditional energy resources become increasingly scarce and their price rises (ibid.). Hence the Cagliari metropolitan area has diverse potential for the geothermal resources, both using the superficial low enthalpy waters for newly built or old single buildings, and researching medium enthalpy conditions or exploiting the most favourable areas and the remote heating systems for mid-size user communities.

The biomass potential estimation can be calculated in every region. Only required data about forested areas which are available for biomass use are requested. Other data, which have to be estimated are the wood extraction capacity and transportation costs. In the eastern metropolitan area should be also important mapping different forest biotopes, because only conifers were mapped by the Forest authority of Sardinia ("Ente Foreste").

Expert weighting of criteria about locating energy efficient residential development in combination with the use of GIS and multi-criteria analysis were useful for supporting the complex planning process. Various experts independently came to a considerable degree of accordance about their general preferences .

The results of the research indicate that this method can incorporate different levels of complexity of the decision problems. Housing development was preferred by experts preferences almost near the Cagliari city and surrounded municipalities. However, the wetlands of Santa Gilla and Molentargius, located near the city of Cagliari, contribute to impact on the micro-climate and affect the urban life quality around them (cf. ZOPPI 2009). Therefore more detailed study at bigger scale about the environmental and landscape impact on the wetlands will be needed, in consideration of the delicate environment system of the Molentargius, where the presence of the salt ponds plays a fundamental role on the quality of the air. Accordingly, the close dependence between the health of the Wetlands and the quality of life of the settled communities highlights the need to pay great attention to their protection and the important relationships between the urban areas and these sensible ecosystems. From this perspective, it should be also remembered that the classification of the Santa Gilla Wetland as "natural reserve" (Regional Law 31/1989) and the creation of the Regional Natural Park of Molentargius-Saline (Regional Law 5/1999) were not sufficient on their own for the question of the Wetlands to become a priority for the territorial development policies of the local administrations, or even for the cultural debate. It must be noted that the method proposed is only a tool for helping decision makers; it is not the decision itself. In fact the selection of possible locations for locating new housing with micro renewable 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 weights of factors were estimated using the analytical hierarchy process (AHP). Constraints were defined as Boolean mask. The land evaluation was performed on a cell by cell basis. The WLC allowed to use the full potential of factors as continuous surfaces of suitability. A limitation using comparison matrices is that if there are too many criteria (e.g. more than 7 for each matrix) matrix will be inconsistent in many cases, because it may be very difficult for experts to express "consistent" opinions by comparing too much criteria. According to this, the choice of factors played a crucial role. Clearly, the criteria selected for housing development and for micro-renewable preferences need to be combined along with other criteria, which depend on analysis conducted at smaller scale. In this context, it will be interesting to compare the landscape plan of Sardinia and the land use plans of the municipalities with the results obtained in this work to identify lucks and limitations.

The proposed method offers some advantages over the classical site suitability analysis techniques. First, it provides a structured approach to derive the suitability by "decomposing" a complex problem into three levels (energy potentials, experts preferences for housing development, 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. Also supplementing the criteria needs considerable effort. Second, this method allow to incorporate criteria, which differ in nature, and gives opportunity to decision makers to enter their own judgments. Third, the approach is very transparent and a suitable way to weight different criteria if no democratic legalized standards are available as a basis for weighting and decision making. Fourth, the general preference and not a special site specific individual interest is relevant, which may help at the same time to support rational decisions especially in local development and achieve a good acceptance. Fifth, if regional /local stakeholder preferences are taken as a basis the methods can be used in order to model the probable future expansion of housing development according to local interests. If mandatory zoning is weak or not existent, land use planning can use this information for strategy building. Sixth, the fact, that the stakeholder involved are given the same weight (one preference corresponds to one weight), may support a better communication among the decision makers and the entire community. On the other hand in representative democracies, decisions about land use planning have to be made by the elected representatives in the limits of the legal framework. Groups with special interests should be heard in the forefront of the decision making.

In the future, more concrete legal standards and priorities for decisions about energy efficient housing and the environment may more strongly confine the importance of the expert preferences. In that case more predefined priorities can be included in the method as well as a combination with conventional impact assessment.

Environmental planners and public authorities often make complex decisions within a short period of time when 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 very useful for supporting fast decisions. Once the maps are available, land planners can analyze any new project by using simple operations such as map overlay or statistical analysis on a given area. This approach led to the identification of conflicting demands as well as sites with the highest energy potential and the 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 points of view and coordinate their policies. Once the maps are available, land planners could analyze any new project by using simple operations such as map overlay or statistical analysis on a given area. Ideally, these maps should incorporate complex criteria integrating several stakeholders' points of view. However, selecting or adding criteria from a list of factors should be an important step for the 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 described in details the implementation of the method proposed that was implemented in GIS environment. The energy potential estimations and a spatial multicriteria decision making (SMCDM) process based on GIS techniques were the main tasks of this thesis work. The method suggests to consider several criteria by using the Multi-criteria analysis for new housing development and for the integration of micro renewable technology. It is compressive and flexible, can be modified to fulfill national and regional needs. These suggestions were tested for implementation on the Eastern Metropolitan Area of Cagliari in the South of Sardinia, which was used as a case study. The main purpose of this application was to suggest the best areas for residential development in testes area.

In this work it was shown that the estimation of potential renewable energy is achievable except for biomass potential with the methodologies available today. Although the proposed approach for estimating micro renewable energy potential at regional/sub-regional scale is still under improvement, the preliminary results encourage continuing the research in this direction. From an operational point of view, the research has experimented with the application of several methodologies, datasets and software to calculate the potential renewable energy for new settlements. For the case study area it was assumed that all the three layers (energy potential, new settlement preferences and micro renewable preferences) were of equal importance and therefore carry the same weight. However, it would be also possible to give more consideration to the energy potential, because the proposed approach is flexible which makes it useful as a planning tool. On the other hand, the users can employ their individual local, national and regional expertise in the decision making process. Such framework allows the incorporation and the accommodation of both qualitative and quantitative criteria for assessing site suitability. Additional layers of information, such as economic considerations, could be easily 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 by achieving desired and as such reducing the complex nature in the planning process allowing different stakeholders to reach a general conclusion. GIS technology provides the capabilities of data acquisition, storage, retrieval, manipulation, and data analysis to develop informations that can support decisions. MCDM technique provide the tools for integrating the geographical data and the decision maker's preferences into one-dimensional value array of alternative decisions. In this work, several advantages of using the analytic hierarchy process (AHP) as a tool while carrying out suitability maps have been highlighted. Some shortcomings and modifications have been described briefly. In this application, AHP has been used for capturing the perceptions of stakeholders on environmental and landscape impacts of each micro renewable technology for future housing development, which may be helpful for public authorities in prioritising their land use or development plans. Therefore, the AHP can be a useful tool for systematically analysing the opinions of several groups of experts belonging to diverse fields.

Nevertheless, the method allows planners and planning authorities to plan alternative settlements based on "non-traditional criteria" evaluating the ecological, social and economical impact of each proposal. Moreover, in the process of weighting the views of all interest groups could be asked with respect to their level of involvement. So this model can increase the public participation in the urban decision making and alternatives could be constructed considering information from several sources, for instance, the participatory process, the review of the projects, technical interviews, and so on.

This approach can be applied in developed and not developed countries. The unplanned physical growth is one the most challenging problems in the developing countries which impose many socio-economic and environmental constraints. So, the physical growth of cities should be guided and controlled by considering the different parameters which influence the city expansion. In view of the growing complexity of managing rapidly evolving cities, in particular in Europe, there is definitely a need for tools that assist regional/urban planners and public authorities in this undertaking. Such an integrated city planning tool can be helpful in monitoring the progress in development of a city in relation to its regional environment, in 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 needs a large amount of data and information which the traditional methods are not able to do deal with them. Not all data could be available but if this missing data was to become available in the future this model could be easily modified to make use of it. Furthermore, better results will be achieved if the process is carried out iteratively, giving the participants a chance to view the energy potential maps to find the best locations. To improve on criteria accuracy, smaller units with more detailed data may considerably improve the results.

In the future the methodology will be improved at urban scale, in particular:

- Estimation of solar energy potential for solar in urban areas using a 3D city model. In fact, in urban installations PV electricity comes from a large number of small power generators that should be distributed over the 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 3-dimensional (3-D) city model of urban areas can be implemented in a GIS database

- Simulation of the wind flow in urban context for wind energy estimation will be a next step. 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 the 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, scale 1:20.000, recently developed by the Region of Sardinia and estimations about the groundwater movement, can be helpful to obtain a more accurate estimation at bigger scale. Furthermore, geothermal maps will be more accurate by providing parameters such as thermal and heat conductivity, borehole thermal resistance as well as more informations and data on geology, hydrogeology and geochemistry. These data regard to formations groundwater parameters (pore volume, pressure head, trasmissivity), groundwater quality of aquifers (salt/sweet, pH, methane), geomorphology, stability of slopes, surface and subsurface drainage. For instance the in-situ geothermal response test provides data on the thermal properties of the ground, e.g. the thermal conductivity and borehole resistance.

- The next step for biomass potential may be the mapping of different forest biotopes. The Region of Sardinia has already mapped the conifers over the region for producing wood, which has been used for heat production in a big power plant in Ottana, province of Nuoro. There are not any programs or plans at the moment about using biomass at a small scale to heat and power homes (e.g. co-generators). Future improvements of the biomass potential estimation will required an accurate estimation of the biomass resource and the development of new methodologies for the estimation of wood extraction capacity and transportation costs for an hypothetical settlement also implemented in a GIS environment.

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

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ANNEX 1: Questionnaire

Contact:
Claudia Palmas
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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?

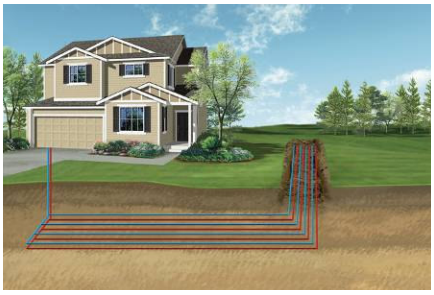
Comparison between..	Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological sites)	Proximity to drinking water or aquifers
Distance from historic/cultural facilities (historical centre, areas of historical and cultural interests, archeological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

………

………

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………

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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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)

$n := 5$

$RI(n) := 1.12$

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

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

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

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

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

$S = -1.731$

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

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

$$\lambda max := 5.354$$

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

$$CI = 0.089$$

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

$$CR = 0.079$$