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An Assessment of the Solar Potential of Roofs within a Web-based Solar Cadastre

Case Study: Bolzano and Bressanone, Italy

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MASTER'S THESIS

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by

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I hereby declare that submitted thesis entitled “An Assessment of the Solar Potential of Roofs within a Web-based Solar Cadastre - Case Study: Bolzano and Bressanone, Italy” represents my original work and that I have used no other sources except as noted by citations. All data, tables, figures and text citations which have been reproduced from any other source, including the Internet, have been explicitly acknowledged as such.

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List of Abbreviations

AJAX Asynchronous JavaScript and XML

a-Si Amorphous silicon

CdTe Cadmium telluride

CIGS Copper-indium materials

DBMS Database Management System

DSM Digital Surface Model

DTM Digital Terrain Model

EURAC The European Academy of Bozen/Bolzano

GIS Geographic Information Systems

GML Geography Markup Language

GUI Graphical User Interface

HTTP Hypertext Transfer Protocol

INSPIRE Infrastructure for Spatial Information in Europe

ISO International Organization for Standardization

JSON JavaScript Object Notation

KML Keyhole Markup Language

LIDAR Light Detection and Ranging

OGC Open Geospatial Consortium

pcSi Polycrystalline silicon

PV Photovoltaic

PVGIS Photovoltaic Geographical Information System

SDI Spatial Data Infrastructure

SRID Spatial Reference System Identifier

UML Unified Modelling Language

UUID Universally Unique Identifiers

WFS Web Feature Service

WMC Web Map Context

WMS Web Map Service

WMTS Web Map Tile Service

XML Extensible Markup Language

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Abstract

In the last decade the energy issue became a crucial component of ecologically and economically sustainable urban development. The conventional energy sources such as oil, gas and coal are tending to decrease, whereas the renewable energy sources such as solar energy, wind power, hydropower, biofuel, biomass and geothermal energy are making a great contribution into producing electric energy, domestic hot water, heating and motor fuels.

Moreover, solar technologies are quite mature already and offer a variety of technical solutions for on-site energy generation. Along with clean and sustainable energy production photovoltaic systems could be installed for a reasonable cost, therefore, their use is growing and private users as well as local authorities demonstrate wide interest in identifying areas suitable for mounting the solar modules.

Based on LIDAR (Light Detection and Ranging), a remote sensing technology, precise surface and terrain models can be constructed for evaluation of solar radiation distribution and shadowing at each location. Furthermore, for photovoltaic potential estimations it is necessary to include the information about ambient temperature and parameters of the considered photovoltaic technologies. To proceed with this assignment, the information should be merged and visualized in a convenient way for the end user, which is not trivial.

The proposed solution includes development of the WebGIS Solar Tirol application, a state-of-the-art technology, which offers immediate access to the information about irradiance distribution, electrical energy, emission savings and photovoltaic output on building roofs within a single environment. Moreover, the approach doesn't require the installation of additional software and uses open-source, data standards and APIs. The tool is implemented in a three layer architecture: user interface, application server and spatial database. Therefore, the contribution of the research includes an integration of the methodology for the solar potential estimations into the Web environment. Moreover, the WebGIS Solar Tirol is developed within an existing SDI that provides easy access for collaboration and distribution of solar potential data.

The objective of the application is to increase environmental awareness among the res-

idents and provide private users and authorities with comprehensive information for the planning and installation of the solar power systems within an intuitive environment. The results represent an preliminary assessment of solar potential characteristics that can be used to support management decisions regarding investments in the solar systems. The research is applied to the study area in the Autonomous Province of Bolzano (Alto Adige / Südtirol), Northern Italy. The region of South Tyrol has great potential for developing solar energy due to a favorable geographic location, political measures and economic instruments designed to improve the energy efficiency. The combination of cool temperatures and large amounts of solar radiation provides ideal conditions for the solar power systems. However, the complex mountain landscape makes an assessment of solar potential challenging.

Keywords: WebGIS; GIS; solar map; solar assessment application; solar cadastre; cities; tool; urban planning; solar resource assessment; PV

Kurzfassung

Im letzten Jahrzehnt wurde die Energiefrage zu einer entscheidenden Komponente der ökologisch und ökonomisch nachhaltigen Stadtentwicklung. Die konventionellen Energieträger wie Öl, Gas und Kohle werden aufgrund der begrenzten Ressourcen tendenziell sinken, während die erneuerbaren Energien wie Solarenergie Windkraft, Wasserkraft, Biomasse und Geothermie einen großen Beitrag in die Produktion von elektrischer Energie, Warmwasser, Heizung sowie Brenn- und Treibstoffe leisten werden.

Dabei sind Solartechnologien bereits sehr ausgereift und bieten eine Vielzahl von technischen Lösungen für die Energiegewinnung vor Ort. Verbunden mit sauberer und nachhaltiger Energieerzeugung können die photovoltaischen Anlagen auch für einen vernünftigen und leistbaren Preis installiert werden. Deshalb wächst das Interesse privater Anwender wie auch der Kommunen, geeignete Bereiche und Flächen für die Montage der Solarmodule zu finden. Basierend auf LIDAR (Light Detection and Ranging), eine Technologie der Fernerkundung, können präzise Oberflächen- und Geländemodelle für die Auswertung der Verteilung der Sonneneinstrahlung an jedem Standort erstellt werden. Weiterhin ist es notwendig für die Schätzung des Photovoltaikpotentials, die Informationen über Umgebungstemperatur und der Parameter der betrachteten Photovoltaik-Technologie einzubeziehen. All diese Informationen sollten zusammengeführt und in einer bequemen Art und Weise für den Endverbraucher visualisiert werden, was nicht einfach ist. Die vorgeschlagene Lösung umfasst die Entwicklung einer Solar Tirol WebGIS-Anwendung, eine State-of-the-Art-Technologie, die sofortigen Zugriff auf die Informationen über Strahlungsverteilung, elektrische Energie, Emissionseinsparungen und Photovoltaik-Leistung auf Gebäudedächern in einer bestimmten Umgebung bietet. Die Anwendung verwendet Open-Source-Standards und ist in einer drei-Schicht-Architektur implementiert: Benutzeroberfläche, Anwendungsserver und räumliche Datenbank. Das WebGIS ist innerhalb eines bestehenden SDI eingebunden, das einen leichten Zugang für die Verteilung der Solarpotential-Daten bereitstellt.

Das Ziel der Anwendung ist es, das Umweltbewusstsein der Bewohner zu erhöhen und private Nutzer und Behörden mit umfassenden Informationen für die Planung und Installation der Solarstromanlagen in ihrer Umgebung zu versorgen. Die Ergebnisse stellen eine

vorläufige Bewertung der Solarpotentialeigenschaften dar, die verwendet werden können um Management-Entscheidungen hinsichtlich von Investitionen in Solaranlagen zu unterstützen. Die Forschung bezieht sich auf das Untersuchungsgebiet der Autonomen Provinz Bozen (Südtirol), Norditalien. Die Region Südtirol hat durch seine günstige geographische Lage, einem stabilen politischen Rahmen und guter ökonomischer Bedingungen eine große Möglichkeit durch die Entwicklung von Solarenergie eine Verbesserung der Energieeffizienz zu erreichen. Die Kombination von kühlen Temperaturen und großen Mengen an Sonneneinstrahlung bieten außerdem ideale Bedingungen für Solarstromanlagen. Allerdings macht die komplexe Gebirgslandschaft eine Bewertung des Solarpotenzials herausfordernd.

Stichwörter: WebGIS; GIS; Solarkarte; Solar-Kataster; Städte; Stadtplanung; Solar Potential Bewertung; PV; Sonneneinstrahlungskarte

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Chapter 1

Introduction

1.1 Motivation

In contrast with the past, the energy issue has become a crucial component of ecologically and economically sustainable urban development. The conventional energy sources such as oil, gas and coal are tending to decrease, whereas renewable energy sources such as solar energy, wind power, hydropower, biofuel, biomass and geothermal energy are making a great contribution into producing electric energy, domestic hot water, heating and motor fuels.

According to European Union directive for 2020 (Parliament and the Council (2009)) the opportunities for establishing economic growth through innovation and sustainable competitive energy policy have been recognised. Thus, it is recommended to the local governments to propagate the strategy of renewable energy sources (Parliament and the Council (2009)). Furthermore, solar technology seems to be an attractive and available choice for European countries and for the Autonomous Province of Bolzano, Italy in particular, due to its favorable geographical location, political measures and economic instruments designed to improve energy efficiency.

Additionally, solar technologies are quite mature already and offer a variety of technical solutions for on-site energy generation. Along with clean and sustainable energy production photovoltaic systems can be installed for a reasonable cost, therefore their use is growing and private users as well as local authorities demonstrate a broad interest in identifying areas suitable for mounting solar modules.

Although utilization of renewable energy, in particular solar energy, is enforced in regional energy strategies, in particular solar energy, is enforced, there is no reliable regional database to plan solar energy installations at a local scale. But how can the homeowners and companies know if their property is well-suited for solar power systems? Of course they

might rely on advice from contractors, however there must be another quicker solution for preview of roof solar power potential. For this reason it is essential to have a tool which allows to calculate the solar irradiance of specific areas. The roof potential measurements can enable solar planners, installers, and property owners to realize significant savings and hasten the workflow of evaluating rooftops and “green” buildings.

Therefore, the first question is how to estimate the solar potential on the roof level. Nowadays active airborne remote sensing is becoming a common way of supporting the estimation of solar potential. Based on Light Detection and Ranging (LIDAR), a remote sensing technology, high-resolution 3D surface and terrain models - Digital Terrain Model (DTM) and Digital Surface Model (DSM) - can be constructed for simulation of incoming solar radiation hitting the roof tops and shadowing at each location. Furthermore, to achieve best results for the photovoltaic potential estimations it is necessary to include information about ambient temperature and parameters of the considered photovoltaic technologies.

To proceed with this assignment, the information should be merged and visualized in a convenient way for the end user, which is not trivial. Moreover, the data produced could be of a heterogeneous type. Therefore, the convenient and successful analysis of large amount of spatial data requires adequate storage, retrieval, integration and visualization of the data. For this reason, the data should be well-organised with the possibility to use it in different formats including vector and raster, perform query operations and spatial analysis. Hence, the development of a WebGIS application within an Spatial Data Infrastructure (SDI) could be an adequate solution.

A WebGIS application is a communication tool with geographical content, that provides a user with a map that can serve to request information. The tool works in two directions. Firstly, it shows the information visually, therefore a user can identify an interesting feature. And secondly, a user can retrieve the detailed information by selecting a feature from the map. Apparently, the WebGIS applications have a particular place in data visualization, therefore this tool can serve as a user-friendly environment to transfer knowledge to the wider public. Consequently, depending on the type of user the tool can be used for planning a solar system in a private or industrial building, urban planning, building renovations, promotion of renewable energy in the region and educational purposes.

1.2 Background

According to Agugiaro et al. (2011), the solar technology provides on-site generation by capturing the energy coming from the sun with solar panels and transforming it into heating or, by means of Photovoltaic (PV) systems, into electricity. When it comes to solar power, not all roofs are created equal. Some face the wrong way, are angled poorly, fall

under the shade of a tree or a taller building. Nevertheless, the number of new photovoltaic installations is tending to increase each year. Although solar technologies are quite mature already and photovoltaic and thermal solar systems are available for private users as well as they have gained high importance for industrial use, there is a lack of information for preliminary estimation of solar power.

South Tyrol is Italy's Green Region - a model province in the renewable energy sector. Due to the favorable geographic location, South Tyrol has a great solar potential. The combination of cool temperatures and large amounts of solar radiation provides with the ideal conditions for solar power systems. However, there are some constraints on massive use of the solar energy.

Firstly, the complex mountain landscape makes an assessment of solar potential challenging due to shadowing. Also, the solar system should fulfill the technical requirements and criteria for architectural integration. Therefore, it is advisable to investigate the potential of the available urban surfaces, where the systems can be integrated into a roof rather than being mounted on the ground on land that could be used for another strategic purpose such as agriculture. Moreover, this task is quite complex and in order to evaluate solar power options many of parameters should be taken into account, for example: azimuth, elevation, shadowing, sunlight intensity and climate impacts.

The recent improvements of remote sensing techniques (sensors, platforms and systems) make them very attractive and capable to contribute to the above mentioned surveying tasks, in terms of geometric resolution, operability and accuracy. In particular, active LIDAR has emerged as an effective technology for the acquisition of high quality DSM, due to its capability to generate dense 3D terrain point cloud data with high accuracy of measurements (Axelsson (1999)).

Hence, this technology was applied to obtain the three-dimensional model of the terrain. The model was derived from high-resolution (0.5 *m* for the main valleys in South Tyrol) LIDAR data and includes the shapes of building rooftops and structures. The dataset is used as a base for evaluating the amount of solar radiation that falls on each unit of surface every half an hour and determining its individual potential for solar electric generation using PV panels.

Apart from the estimation of the solar potential, it is of paramount importance to transfer the knowledge to the public. There are plenty of tools that can represent the data; however, WebGIS can provide a convenient and comprehensive way to communicate the information. The WebGIS environment is state-of-the-art technology, which offers access to the information that integrates different data sources and a wide audience of users can retrieve the details about an object in the single user interface with no need for additional software installation. Besides, based on the open-source software and APIs, there is a big potential

to create rich and interactive applications.

1.3 Proposed Solution

The actual research is aimed at the implementation of the methodology for solar potential estimation within the Web environment, storing and sharing the data and metadata within existing SDI, and eventual visualization of solar information on the building roofs. The WebGIS can provide communities with information that will drive sustainable practices, community awareness, energy efficiency and smart development.

The solution includes work on the combination of vector and raster data that allows evaluation of the incoming solar radiation hitting the roof tops. The initial data, the DTM and DSM, are derived from the LIDAR data and provided within the project “Solar Tirol” as the input information for solar radiation simulations. The resolutions of the models are 0.5 m for the main valleys and 25 m for the other regions. Additionally, the main data sources are cadastre data, ambient temperature grid and vector data of protected areas.

Moreover, in the actual research the contribution is narrowed to the following aspects:

- To develop the implementation of the complex methodology for estimation of solar potential characteristics into Web environment.
- To create a model of the geo-referenced solar potential database, which can allow private users to identify the solar potential of roofs.
- To develop the running WebGIS application based on the open software within a user-friendly environment.
- To implement the WebGIS into existing SDI.
- To evaluate possible constraints and approximations.

The Solar Tirol WebGIS application includes digital basemaps, operational layers, tools and a geodatabase. Furthermore, Google, Bing, and Open Street Map APIs are used as based layers, where users can find the familiar interfaces of a street map, terrain or hybrid representation. The operational layers represent the information about insolation, cadastre data and protected areas. As regarding the tools, they are defined according to user needs and include basic tools as pan and zoom as well as more measuring tools. Moreover, the WebGIS Solar Tirol is developed within SDI EURAC that provides easy access for collaboration and distribution of solar potential data. Therefore, the SDI technology can bring significant benefits for public organizations, local authorities and the private sector. Moreover, the SDI supplies simple, interactive, and flexible access to geospatial data via Web services. In addition, the SDI EURAC framework is based on industry standards, which include the stan-

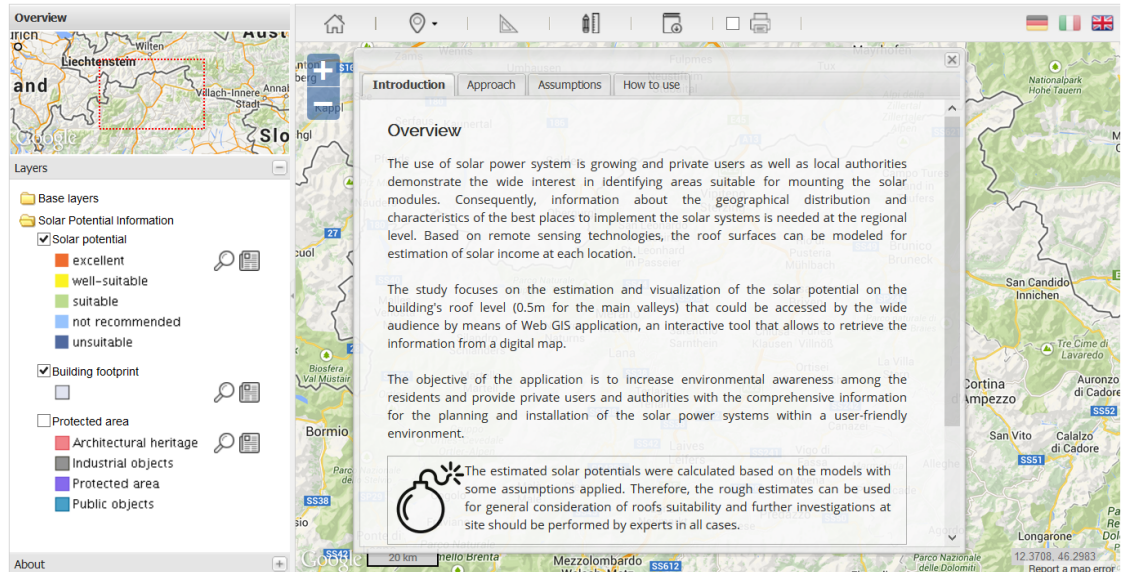


Figure 1.1: The WebGIS “Solar Tirol” that was developed in the actual research is available at <http://webgis.eurac.edu/solartiro1/>

dards defined by Open Geospatial Consortium (OGC), Infrastructure for Spatial Information in Europe (INSPIRE), and the International Organization for Standardization (ISO).

Furthermore, the Geographic Information Systems (GIS) model is based on remote evaluations and simulation methodologies, therefore, the results may be imprecise due to resolution limitations, unreliable cadastre data, presence of vegetation, model inaccuracy, non-modeled impacts, undetectable constructions, incomplete or corrupted GIS layers or database. In analysing the work, some important assumptions should be taken into account:

- Cloud correction is not applied to the solar radiation data in the following work. It can lead to overestimated results, since the simulation is applied on clear sky. Cloud correction will be accounted for in future work.
- cadastre data for city of Bozen and Brixen dates to 2006. However, due to the fact that it is an official data source, it must be used. The obsolete cadastre data causes inaccuracy in building footprint representation.
- the use of cadastre data assumes that roof surface is equal to footprint surface. For more accurate results, roof surfaces should be extracted from the LIDAR data and merged with the cadastre data. This work can be done in future development, since the most important issue of this study is to define the methodology of potential estimations within the WebGIS environment,

- sub-roof surfaces are defined by the geometrical principle, however some surfaces could not be detected or were detected wrongly,
- information about existing solar panels is not always accessible, therefore the plane surfaces with installed solar panels could show misleading results,
- potential characteristics are not calculated with the same temporal resolution as the insolation data, therefore the results could be slightly influenced.

Nonetheless, the assumptions are subject to change in the future development. Apart from that, even using measures with high precision, the Web GIS application is made for a preliminary overview of the results by applying some assumptions therefore on-site investigations are needed in each case.

To sum up, the following study focuses on the implementation of GIS methodology for estimation and visualization of the solar potential on the building roofs which could be accessed by a wide audience by means of a WebGIS application, an interactive tool that allows retrieval of the information from a digital map.

The objective of the application is to increase environmental awareness among the residents and provide private users and authorities with comprehensive information for the planning and installation of solar power systems within a user-friendly environment.

The research is applied within the study area in the Autonomous Province of Bolzano (Alto Adige / Südtirol), Northern Italy. South Tyrol is a mountain region with a total surface area of 7400.43 km² (South Tyrol in figures (2013)), 504.643 habitants (2011) and various climate zones. Initially, the research should have been carried out for the whole South Tyrol, however it was decided to scale down the area to the cities of Bozen / Bolzano and Brixen / Bressanone, due to the high computation effort needed for processing the original data, which was produced for the main valleys in South Tyrol.

Moreover, the actual research has been conducted within the framework of the project called "Solar Tirol: Solarpotenziale im Land Tirol und der Provinz Bozen" organised by Land Tyrol and the Autonomous Province of Bolzano in collaboration with EURAC research.

The structure of the work guides the reader from the theoretical background to the practical part of the research. First of all, in the introduction chapter the selection of the question is justified. Furthermore, the literature review reflects main trends and the state-of-the-art. The methodology chapter describes the approach of solar potential estimation. The data models and database design are discussed in a separate chapter, where the information about data sources, data modelling, SDI components, and database design can be found. Within the next chapter the process of implementation of the WebGIS application along with system requirement specifications are explained. Results and analysis, conclusion, discussions and future work are reported.

Chapter 2

Basic Concepts and Literature Review

To perform the research it is important to review the previous works and identify the state-of-the-art. Since the actual research covers several aspects that should be summarized, the following chapter includes two parts:

- Approaches and tools of solar potential estimations. The discussion focuses on the input information for solar potential estimations and techniques for the data processing;
- WebGIS implementations in solar potential projects. In following part the state-of-the-art WebGIS application are examined.

2.1 Approaches and Tools of Solar Radiation Estimations

Active airborne remote sensing technique is becoming a common way of supporting estimation of solar potential of the roofs. LIDAR is an independent technology which is highly automated to produce DTM and DSM. It is a laser-based approach to emit and capture the returned signal from the topographical surface (Ackermann (1999)). The working principle is explained in the figure 2.1 (Lillesand et al. (2007)). Using the LIDAR data it is possible to construct an accurate 3D surface model by considering returns. The LIDAR processing could be handled by variety of software components as for example LAStools software suite which is available for ArcGIS (versions 9.3, 10.0, 10.1, 10.2) and for QGIS (versions 1.8, 2.0, 2.2, 2.4). Besides, there is a LIDAR module for GRASS GIS as well as for SAGA GIS. Therefore, based on DTM and DSM the solar accessibility analysis at different elevations could be performed.

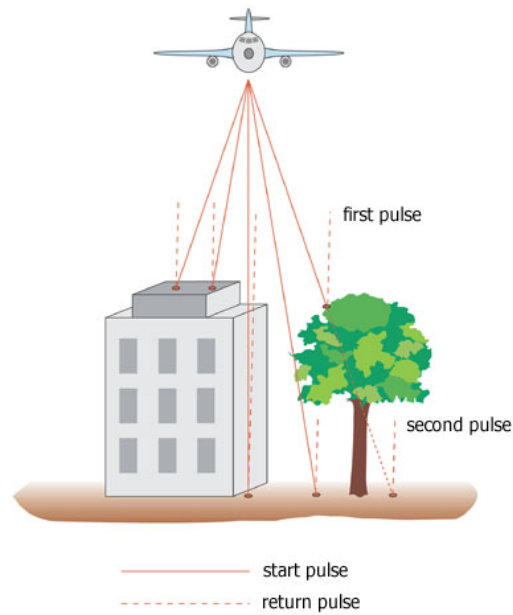


Figure 2.1: LIDAR measurements (the figure from <http://www.terraimaging.de>). The sensor emits laser pulses, that hits the surface and returns some energy back to the sensor, therefore the reflectance can be detected by the receiver of the sensor. Furthermore the difference between emission and reflectance can be found as well as the intensity of the return signal. The measurements are done perpendicular to the flight direction.

The assessment of photovoltaic potential using LIDAR data has been addressed by many authors using different approaches with various levels of complexity. For example, according to Agugiaro et al. (2011) a multi-scale solar radiation estimation on building roofs in mountain areas is proposed. The methodology combines 3D data ranging from regional scale to the architectural scale, where both the terrain and nearby shadowing effects are considered. The research is also focused on evaluation of solar radiation maps obtained from the different geometric models. The models have their own peculiarities in terms of geometric resolution and accuracy, therefore they deliver slightly different results (Agugiaro et al. (2011)).

Furthermore, Nguyen et al. (2012) provide a methodology for the application of LIDAR to automated solar PV deployment analysis on a regional scale. This methodology can enhance consistency and integration with cross-disciplinary competences in remote sensing, GIS, computer vision and urban environmental studies.

Another comprehensive solar potential assessment using a solar radiation model and climatic data was developed by Joint Research Centre in the framework of the project Photovoltaic Geographical Information System (PVGIS) and proposed by Huld et al. (2012).

This research deals with the raster data at 1 km grid size cell. The dataset consists of monthly and yearly averages of global irradiation and related climatic parameters. This study could provide the results at resolution ranging from 1 m to 25 cm. The authors mention that the shadowing effect from nearby vegetation was not taken into account. The model requires only a few mandatory input parameters: DTM (elevation, slope, aspect), day number and local solar time.

When it comes to assessment of solar potential there are plenty of tools available for estimation of the amount of solar irradiance. In order to simulate the solar radiation distribution several factors should be taken into account. The simulation tool should compute the beam (direct), diffuse and ground reflected solar irradiation raster maps for a given day, latitude, surface and atmospheric conditions. As it can be seen from the figure 2.2, the solar radiation for a given day should be computed by integrating the relevant irradiance that represent a curve between sunrise and sunset times for that day.

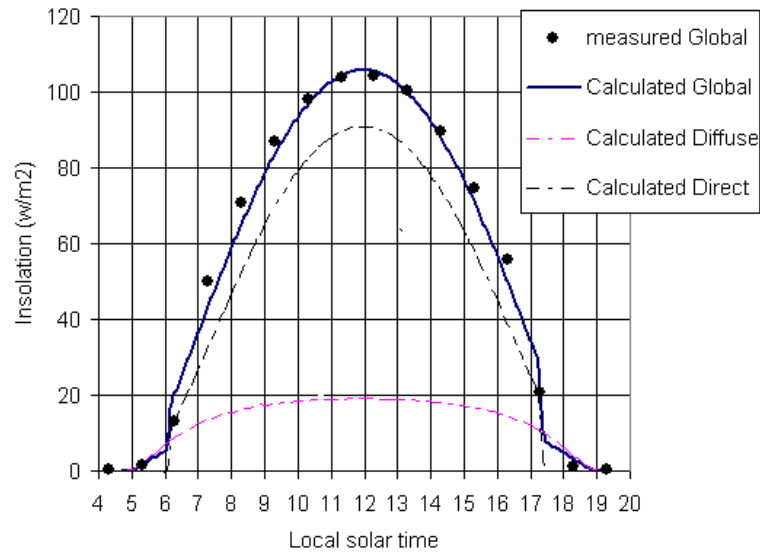


Figure 2.2: Insolation day curve (the figure from Fu and Rich (1999)). The solar radiation distribution throughout the day is heterogeneous, therefore the simulation during the solar hours should be performed in order to estimate the hourly irradiation. The algorithm should include all three components of global radiation (beam, diffuse and reflected).

Due to the fact that topography is a very important factor influencing the distribution of insolation, it should be taken into account in particular for the mountain regions. Therefore, the shadowing could be calculated from DTM using information about horizon height. As far as the atmospheric conditions are concerned, the computations could be done considering a clear sky that means that no atmospheric impacts are considered or real sky that takes

into account the cloudiness for example. Moreover, the Linke atmosphere turbidity factor is a crucial parameter too. According to Kasten (1996) and World Meteorological Organization (WMO) (1981) the Linke turbidity factor is an approximation that accounts for atmospheric absorption and scattering of the solar radiation under clear skies. It describes the optical thickness of the atmosphere due to both the absorption by the water vapor and the absorption and scattering by the aerosol particles relative to a dry and clean atmosphere. As for example, the Linke factor for an absolutely clear atmosphere is equal to 1.

There is a bunch of different tools that allow to perform the GIS simulation of solar irradiance during the given time, however some of them belong to corporate and some to volunteer based projects. According to Hetrick et al. (1993) the SolarFlux model can simulate the influence of shadowing on direct insolation at time intervals. This model was created on the basis of ARC/INFO GIS platform (ESRI), and have been widely used by researchers of diverse fields. But this model is limited by the computation speed of ArcMacro Language and simplistic diffuse calculations. Moreover, it is available only for high-cost GIS software (Fu and Rich (2002)).

Besides, SOLEI model, which was created under MS Windows and connected to IDRISI, corporate software, could calculate potential energy income to the slopes with different orientation and taking into account the shadowing of the surrounding topography (Mészáros et al. (2002)).

Brito et al. (2012) claim to use LIDAR data and the extension “Solar Analyst” within ArcGIS, corporate software, for modeling of solar radiation. This extension enables the mapping and analysis of solar irradiation over a geographic area for specific time periods. According to Fu and Rich (1999) Solar Analyst models the solar radiation using the hemispherical viewshed model (see the figure 2.3). Therefore, the viewsheds are the angular distribution of sky obstruction and they could be calculated for each cell of the input DEM. The Solar Analyst accounts for atmospheric effects, site latitude and elevation, inclination (steepness or slope) and orientation (compass direction or aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding buildings and topography (Brito et al. (2012)).

Carneiro et al. (2009) started by developing a 2.5D urban surface model from LIDAR data, 2D vector digital maps of buildings footprints and alphanumerical data containing altimetric information about buildings heights. The insolation at each data point is calculated using a Matlab routine considering irradiance values (clear sky conditions only) obtained from statistical analysis of local historical data. The application of this method is not limited to roof area as it allows the analysis of the PV potential of building facades.

The mentioned approaches are based on high-cost GIS software. On the other hand, there is an free-based solution proposed for PV potential assessment using r.sun radiation

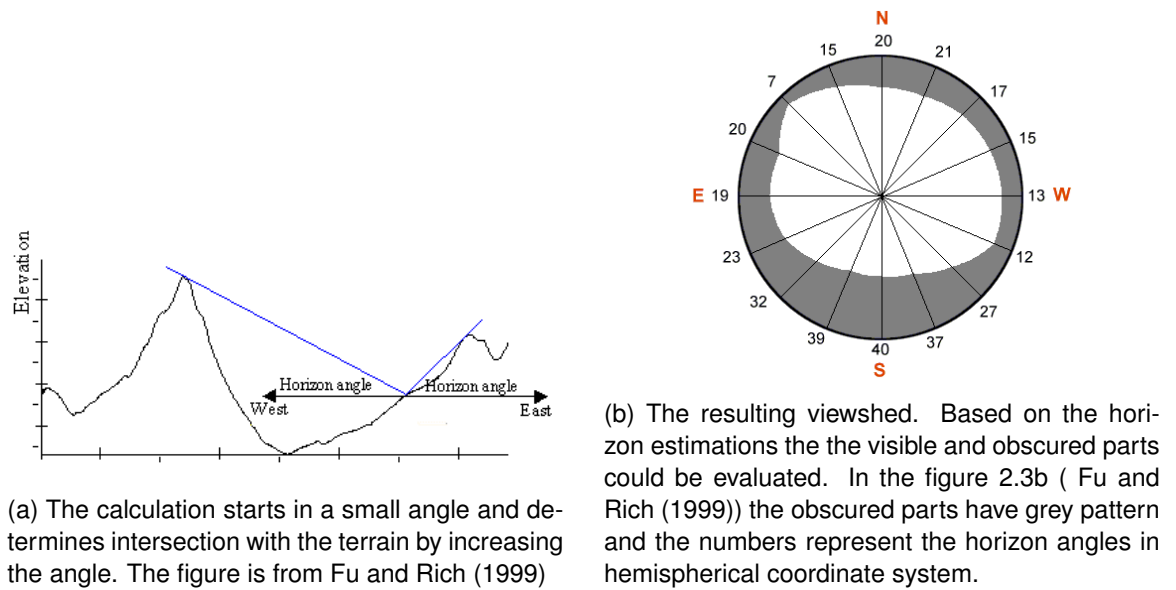


Figure 2.3: Solar Analyst hemispherical viewshed model

model provided by the open source GRASS GIS (Neteler and Mitasova (2004)). The *r.sun* module computes direct, diffuse and reflected solar irradiation raster maps for a given day, latitude, surface and atmospheric conditions. As it is reported by Neteler and Mitasova (2004), the model can consider a shadowing effect of the local topography. This can be done either by calculating the shadowing effect directly from the digital elevation model or using rasters of the horizon height. At first, the *r.sun* program calculates for a solar incidence angle for the local time and solar irradiance values. Then daily sums of solar radiation are computed within a set day. The model accounts for sky obstruction by local relief features. Moreover, the program uses the Linke atmosphere turbidity factor and ground albedo coefficient that help to improve the estimations. Therefore, the PV estimations in the current research are done using GRASS GIS, since one of the requirements is to follow philosophy of open-source. This method uses DSM and DTM, created from LIDAR data for example, and it takes into consideration shadowing, orientation and inclination of roof tops, and it models beam, diffuse and reflected irradiation (Šúri et al. (2007)).

2.2 WebGIS Implementations in Solar Potential Projects

According to Kanters et al. (2014), solar map or solar cadastre is a GIS system providing the annual solar irradiation on building surfaces (roofs and / or facades), along with the information about solar thermal or photovoltaic systems, and connected to a website. Therefore,

many city administrations already have solar maps that mainly serve two purposes: as a front - end platform to inform citizens about the potential of their own roof, and as a back - end tool for city administrations to base energy decisions upon Kanters et al. (2014).

As it was underlined by Mitchell (2005), with the help of the Internet and accompanying tools, creating and publishing on-line maps has become easier and rich with options. The interactive maps offer a marvelous way to display the information that lets users take action. The use of interactive maps brings a lot of opportunities to visualize all sort of data on a digital map, hence the WebGIS is a instrument that helps to provide municipalities, government agencies, utilities, transportation agencies, communications service providers, mapping firms, engineering consultants, engineering contractors and private users with information that is presented in convenient and interactive way. Therefore, the WebGIS could serve as a tool to present the information, to educate users in a particular sphere or to help in decision-making.

A standard WebGIS application includes digital basemaps, operational layers, tasks and tools in the WebGIS application, one or more geodatabases (ArcGIS Help 10.2, 10.2.1, and 10.2.2 (2014)). Moreover, Google, Bing, Open Street Map APIs could be used as based layers, where users can find familiar interface of a street map, terrain or hybrid representation. The operational layers represent thematic layers. As regards the tools, they could be defined according to user needs.

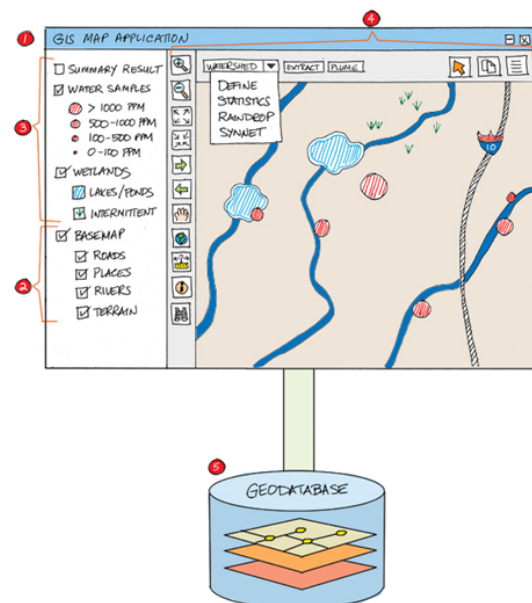


Figure 2.4: A WebGIS application (1) elements includes: digital basemaps (2), operational layers (3), tasks and tolls in the WebGIS application (4), one or more geodatabases (5) (the figure from ArcGIS Help 10.2, 10.2.1, and 10.2.2 (2014)).

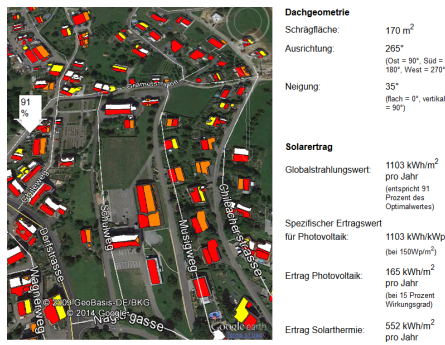
The rapid development of Web mapping is bringing new technologies into digital cartography. The recent developments give an access to the open source solutions as OpenLayers, Ext.js, Geoext.js, JavaScript for dynamic web content creation that can be displayed on every major browser on the market. Besides, the applications could be supported by Geoserver, which helps to share the spatial information, Database Management System (DBMS) PostgreSQL and its extension for spatial information PostGIS, and Mapserver that creates from the spatial data corresponding images.

As a result, the development of a WebGIS application seems to be a choice for displaying solar power information that can help to promote the use of it. Besides, the solar potential data could be visualized on a user-friendly environment with no need for further software installations. Moreover, the information can be shown on a big scope, consequently it is easier to evaluate the size of the regional solar industry.

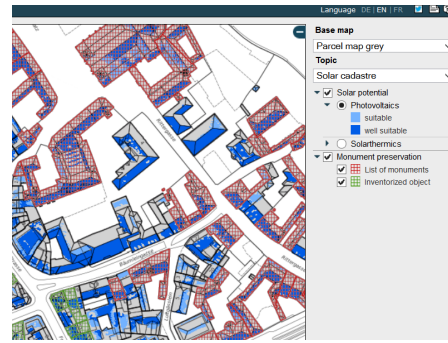
Hence, there is a variety of dynamic and interactive GIS-based solar cadaster mapping systems available on the Web. Generally speaking, the Web technologies are developing rapidly and the applications that are mentioned in the research can be out-of-date by the time of reading the thesis. Nevertheless, some of the examples of Solar Cadaster WebGIS applications could be considered as state-of-the-art at the time (see the figure 2.5).

Solar Cadaster application developed in Switzerland illustrated in the figure 2.5a provides the solar potential data visualized on Google Earth. Using an interactive tool, a user can insert some parameters and calculate an approximate consumption and benefits in case if the PV or domestic water heating is installed. In order to produce the irradiation simulation, an average global radiation value that is accessed via the PVGIS for the municipality was used. According to description, DTM and building footprints were the major input data, however the contours of the roof surfaces are derived automatically. The drawback of the application is that small chimneys and other objects on the roof level are not considered, but only the main roof surfaces. The irradiation simulation is performed for an interval in 1 h over a whole year and the incident solar radiation is summed per roof surface, whereas for the current research calculations were performed with the interval in 15 minutes.

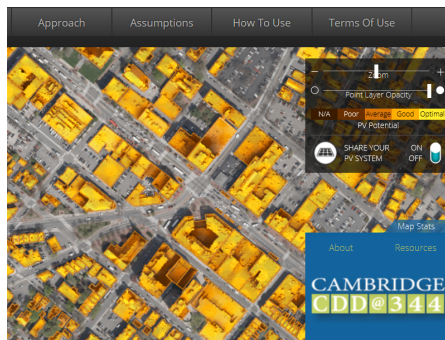
Another interesting application was produced by city of Basel that includes aggregated data on a cadaster parcel level. Besides, it includes information about registered monuments and recommendations for the solar planners (figure 2.5b). Calculations of Solar global radiation are based on 0.5 m-surface model carried out by the laser-scan overfly. The contours of buildings are based on the level ground coverage of the official survey, the roof edges on the 3D city model. The application offers the information about PV and Thermal potential. As it was described by Kanters et al. (2014), the city of Basel launched an environmental program where they encourage people to first renovate their roofs, and then install PV if their roofs had the right conditions based on provided subsidies. Moreover, the



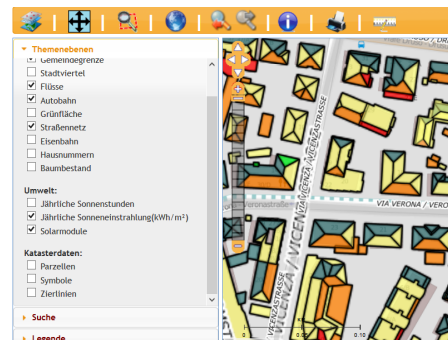
(a) Solarkataster.ch, Switzerland



(b) Solar Cadastre, Basel Stadt, Switzerland



(c) Mapdwell Solar System, Cambridge



(d) SitSun, Bolzano, South Tyrol

Figure 2.5: Examples of WebGIS Solar Cadastre: (a) Solarkataster.ch, Switzerland provides with Photovoltaic and Solar Thermal outputs in 3D view; (b) Solar Cadastre, Basel Stadt, Switzerland includes information about registered monuments and recommendations for the solar planners; (c) Mapdwell Solar System, Cambridge allows to calculate the cost and benefits taking into account taxes with the information about further monthly revenue; (d) SitSun, Bolzano, South Tyrol lets retrieve information of suitability for the installation of solar modules

city also approached the owners of the 500 best roofs to implement PV.

Furthermore, the Mapdwell Solar System Project allows to calculate the cost and benefits taking into account taxes with the information about further monthly revenue (figure 2.5c). Moreover, the application allows the individuals to contribute to the project by sharing the information about installed PV systems.

What's more, the application PV initiative (figure 2.6) was created for the public and administration of city of Brixen. The WebGIS shows the annual availability of the solar resource on the different roofs. The estimations didn't consider clouds and aerosols. In order to account for the real atmospheric conditions a calibration of the model has been performed by using the 30-years measurements of solar radiation registered in the meteorological station of Laimburg. The specific information regarding the irradiance and photovoltaic potential could be obtained just by clicking directly on the roof of the building. A color-coded map

shows in three dimensions the best spots to place PV panels.

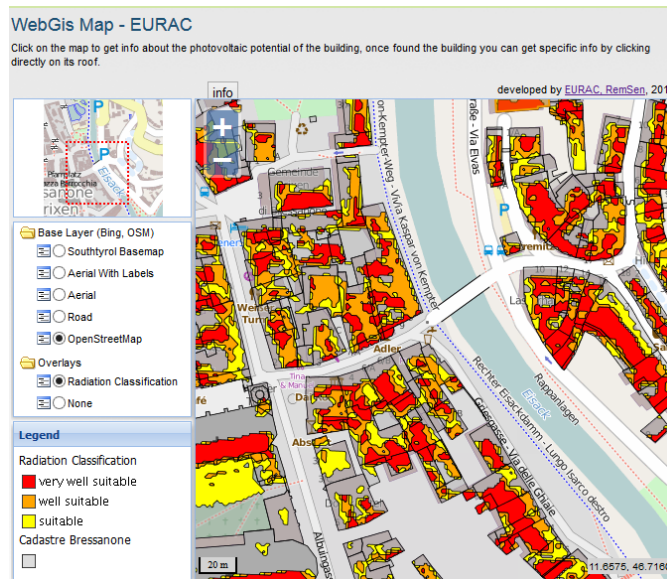


Figure 2.6: PV-initiative, Brixen, South Tyrol. The application PV initiative was created for the public and administration of city of Brixen. The WebGIS shows the annual availability of the solar resource on the different roofs.

However, it is not the only WebGIS application that was created for South Tyrol in the topic of solar potential. Another application was developed by city of Bolzano within the project “SitSun” (figure 2.5d), which lets retrieve information of suitability for the installation of solar modules. The application provides the citizens with an access to simple, quick and dynamic Web environment. Therefore, the following information is available within the application: roof area, building heights, azimuth, slope, sun hours, irradiance and building profile. Basically, a user can chose between two options - solar hours during the day and and irradiance during the year in kilowatt hours per square meter.

The overview with compact description of the state-of-the-art applications is given in the table 2.1.

2.3 Summary

Therefore, according to the analysed study cases the most common approach for identifying the suitable roof surfaces is using LIDAR data as a basis for producing high resolution DTM and DSM. Then, based on the 3D models the further estimations of photovoltaic parameters could be performed.

Table 2.1: Solar Cadastre WebGIS applications

Name and Extent	Description	Approach
Solarkataster.ch, Switzerland	3D building visualization, calculation tool which allows to insert the user data.	<ul style="list-style-type: none"> ✓ Global radiation value ✓ Irradiation simulation ✓ Shading × LIDAR data
Mapdwell Solar System, Cambridge, MA	Estimation of Cost to Owner and Average Monthly Revenue. Crowd-Sourcing.	<ul style="list-style-type: none"> ✓ LIDAR data ✓ Irradiation simulation ✓ Shading ✓ Chimneys, small surfaces
Solarpotenzialkataster, Vienna	the radiation energy is available as a grid, in which radiation above $900 \text{ KWh}/\text{m}^2$ and year are reported.	<ul style="list-style-type: none"> ✓ LIDAR data ✓ Irradiation simulation ✓ Shading ✓ Chimneys, small surfaces
New York Solar Map	The model is based on the position of the sun, overall atmospheric conditions, latitude, shading. Aggregated information could be extracted by a polygon. Calculate Financial Payback	<ul style="list-style-type: none"> ✓ LIDAR data ✓ Global radiation value ✓ Irradiation simulation ✓ Shading
PV initiative, Brixen, Italy	The application takes into account 4 technologies: high efficiency crystalline silicon, standard crystalline silicon, cadmium telluride (CdTe) or copper-indium materials (CIGS) and amorphous silicon (a-Si) double junction	<ul style="list-style-type: none"> ✓ LIDAR data ✓ Irradiation simulation ✓ Shading
Stadt Bozen Solar Kadaster, Bozen, Italy	The application provides the details about heights of the building and sun hours	<ul style="list-style-type: none"> ✓ LIDAR data ✓ Irradiation simulation ✓ Solar hours ✓ Azimut and Slope

Moreover, Kanters et al. (2014) conducted an analysis of the existing Web-based solar maps. Within this research the owners of the Web solar cadastre services were contacted to obtain additional information. As the result, the main focus of the solar cadastre applications is on the following aspects:

- Annual solar irradiation (KWh/m^2);
- Considered applications (Photovoltaic, Solar Thermal);
- Total output per roof ($KWh/area$);
- Assumed efficiency of the technologies;
- Heritage limitations (are buildings with a cultural heritage marked?);
- Threshold value per category (KWh/m^2);
- Minimum surface of solar system (m^2).

Chapter 3

Methodology

The purpose of the methodology chapter is to provide the information about approaches that are used within the following research in order to estimate solar irradiance on building roofs. The methodology includes the combination of vector and raster data that lets evaluate the incoming solar radiation hitting the roof tops. The methodology for estimation of solar potential is validated by the Institute for Renewable Energy, The European Academy of Bozen/Bolzano (EURAC), that performed empirical work for it, therefore, the main goal of the actual research is to implement these methods within the WebGIS application using open-source solutions.

3.1 Estimation and Visualization of Solar Potential Data

Preparatory work

Information about topography is provided by the DTM and DSM, derived from high-resolution (0.5 m for the main valleys in South Tyrol) LIDAR data that was processed by a cooperating company. For the estimation of irradiance in a particular area it is necessary to consider the spatial distribution of the objects and their geometries, cloudiness, water vapour concentration, aerosol, gas absorption and temperature. The DTM and DSM were reprocessed by a responsible party using `r.sun` module within the open-source software GRASS GIS for estimation of solar irradiance, the power of electromagnetic radiation per unit area (radiative flux) incident on a surface (Wh/m^2). The processing was performed according to a tiling system that was introduced for this purpose.

According to Šúri and Hofierka (2004) the solar radiation, incident to the earth's surface, is a result of complex interactions of energy between the atmosphere and surface. Therefore, there are some factors influencing the solar radiation as the position of the Earth with

respect to the sun, atmospheric impacts and terrain surface. The `r.sun` module allows to account for all these three factors. Based on GRASS Development Team (2012) `r.sun` module computes direct (beam), diffuse and reflected solar irradiation raster maps for a given day, latitude, surface and atmospheric conditions. The working routine allows to save solar parameters (e.g. sunrise, sunset times, declination, extraterrestrial irradiance, daylight length) in the map history file. Alternatively, the local time can be specified to compute solar incidence angle and/or irradiance raster maps. The shadowing can be calculated directly from the digital elevation model or using rasters of the horizon height. The horizon rasters can be constructed using `r.horizon` (GRASS Development Team (2012)). The module `r.horizon` performs horizon angle computation from a digital elevation model.

Therefore, in order to start the `r.sun` simulation it is beneficial to have bigger tiles of input DTM and DSM due to the fact that the estimation of horizon maps should include the adjacent area (and therefore their shadows) in the model for the better result. The shadowing is particular important to consider in the mountain regions with complex landscapes. Moreover, the aspect and slope maps could be calculated from the DSM.

During the estimations some correction factors should be taken into account as Linke turbidity, ground albedo coefficient and cloud correction. According to Kasten (1996) and World Meteorological Organization (WMO) (1981) the Linke turbidity factor (TL, for an air mass equal to 2) is a very convenient approximation to model the atmospheric absorption and scattering of the solar radiation under clear skies. It describes the optical thickness of the atmosphere due to both the absorption by the water vapor and the absorption and scattering by the aerosol particles relative to a dry and clean atmosphere. It summarizes the turbidity of the atmosphere, and hence the attenuation of the direct beam solar radiation. Cloud correction is not considered in the estimations during the following research, however in the future work it can be available as mask information or integrated into the data. Therefore, the insolation, the incoming solar radiation that reaches the earth and the atmosphere (W/m^2) values could be accessible as “raw” and corrected. Eventually, the 365 raster datasets with the total daily radiant energy (Wh per m^2) should be summed up with the granularity in one month.

To estimate the daily irradiation for a given region for a given day of the year at 5m resolution the following command can be executed. Here day 172 (i.e., 21 June in non-leap years). An example of output raster can be seen in the figure 3.1:

```
g.region rast=elev_ned_5m -p

# considering cast shadows (-s)
r.sun -s elev_ned_5m lin=1.0 alb=0.2 day=172 \
    beam_rad=b172
```

```
diff_rad=d172 \
refl_rad=r172
insol_time=it172

d.mon x0
# show irradiation raster map [Wh.m-2.day-1]
d.rast.leg b172
# show insolation time raster map [h]
d.rast.leg it172
```

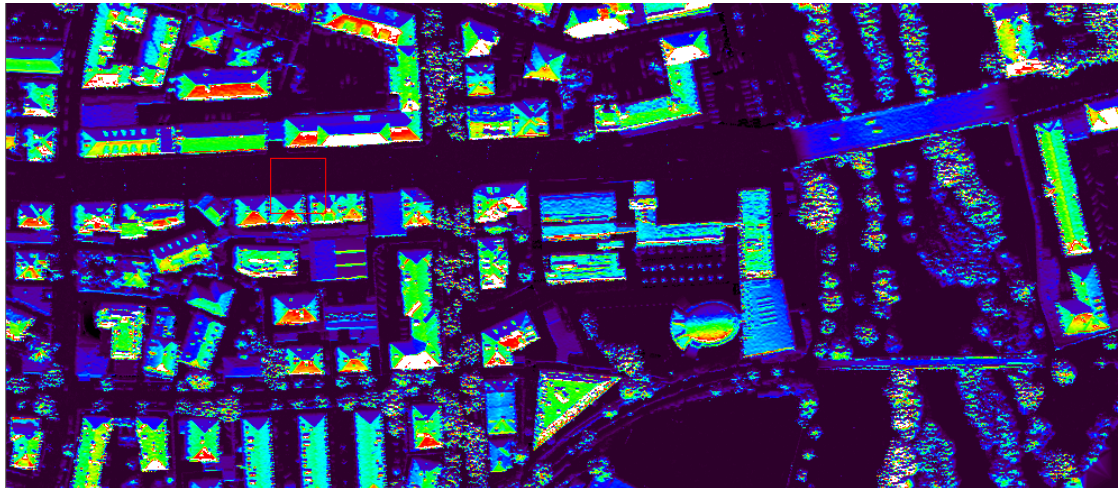


Figure 3.1: Daily mean global irradiance. Calculation of the integrated daily irradiation with Linke turbidity equal to 1.0 for a region in Bolzano, South Tyrol for a given day of the year at 5m resolution. Here day 172 (i.e., 21st June in non-leap years). In total the sum of daily mean global irradiance raster reaches 365 and the sums for each month could be performed.

To sum up, total daily irradiation (Wh per m²) is computed by the integration of the radiant energy (W/m²) calculated at regular time intervals over the day. For each time-step, the computation accounts for sky obstruction by local terrain features (hills or mountains), calculated from the DTM. Moreover, some other outputs could be produced, namely sunrise, sunset times, declination, extraterrestrial irradiance and daylight length. Therefore, the input information for the further estimations is provided as 365 rasters of daily mean global irradiance estimated using *r.sun* module within GRASS GIS with applied coefficient of Linke Turbidity. Afterwards, the sums for each month are calculated.

Solar potential estimation

In the following section the methodology of solar potential estimation is explained. These methods are further implemented within WebGIS environment with no need to estimate all

these parameters in a GIS software.

The estimations are based on two the most usable and mature photovoltaic technologies CdTe and Polycrystalline silicon (pcSi) that have cell efficiency about 10 and 14 percents respectively. The technology pcSi is considered as the only technology that had already been matured to industrial production so far (Becker et al. (2013)). According to Becker et al. (2013) the pcSi benefits from the advantages of the crystalline silicon material along with thin-film technologies. Besides, this material is non-toxic with high stability and durability which has ability to perform high cell efficiencies. However, according to Dustin Mulvaney (2011) the CdTe solar cells differ from crystalline silicon photovoltaic technologies in that they use a smaller amount of semiconductor, a thin film to convert absorbed light energy into electrons. Although the CdTe solar cells are less efficient than crystalline silicon cells, they can be cheaper to produce, and the technology has the potential to overcome silicon in terms of cost per kilowatt of installed capacity. Other technologies are not considered, since the empirical work within the Institute for Renewable Energy, EURAC was performed for CdTe and pcSi. Further investigations will require a complex process of preconditioning that goes beyond the scope of the project.

When it comes to estimation of photovoltaic potential it is necessary to implement a reliable algorithm that works with different technologies. There are several approaches to convert the incoming solar radiation into electricity produced by photovoltaic modules. The easiest option is the constant efficiency method given by the following equation, which is considering the insolation H (W/m^2) and absolute efficiency of a module η :

$$E = \eta \cdot H \quad (3.1)$$

, where E is the total energy produced over a certain period of time, η is the efficiency of the PV module and H is the insolation (solar energy) over a certain period of time.

Although, it is the simplest approach, the constant efficiency method does not include losses unless a reduced value of η is used. In order to achieve better results it is essential to use more complex algorithm that can take into account several variables. In particular temperature of the module, ambient temperature and I irradiance dependency.

Thus, the output electrical power P_{pv} (W/m^2) of PV module that is a function depending on T_{mod} and I is calculated using the equation 3.2:

$$P_{pv}(I, T_{mod}) = \frac{E_{STC}}{A} \cdot \frac{I}{I_{STC}} \cdot \eta_{rel} \quad (3.2)$$

, where P_{pv} is output electrical power (W/m^2), I is irradiance (Wh/m^2), T_{mod} is the module temperature, E_{STC} is nominal power in standard test conditions measured in W , A

is area of the module, I_{STC} is 1000 W/m^2 and η_{rel} is relative efficiency,

The losses effect, namely relative efficiency η_{rel} is not a constant value. There is a strong correlation between the temperature effects and the efficiency. From the physical point of view the spectral distribution of the light should have a great impact on the efficiency too. Nevertheless, for the monthly and yearly averages these effects are nearly canceled out (Moser et al. (2013)). For this reason only the module temperature and irradiance effect are considered. To calculate the efficiency, six coefficients k_1, \dots, k_6 , derived within SoLaRE-PV (see the figure 3.2) (South Tyrol Laboratory for renewable energy-PV, Institute for Renewable Energy, EURAC), were taken into account (see the table 3.1). To determine the coefficients, performance matrices were measured in the SoLaRE-PV lab and fitted with the chosen model (see equation 3.2). A performance matrix is built with a series of power measurements at different values of irradiance I , and module temperature T (see the figure 3.3). By knowing the six parameters k_1, \dots, k_6 , it is now possible to calculate a value for P at different conditions of I and T .



Figure 3.2: Sun simulator and the climatic chamber, PV-SoLaRE Lab at EURAC, Bolzano. The simulator can perform the assessment of the characteristics and performance of photovoltaic modules based on different technologies.

The relative efficiency η_{rel} is dependent from changes in temperature, irradiance and spectral effects. Although, the influence of the effects is not considered, it can have an impact for the investigation period in less than a year. Furthermore, the estimation of the efficiency depends on the temperature effects and irradiance (see the equations 3.3, 3.4 and 3.5):

$$\eta_{rel} = 1 + k_1 \cdot \ln(I') + k_2 \cdot (\ln(I'))^2 + T'(k_3 + k_4 \cdot \ln(I') + k_5 \cdot (\ln(I'))^2 + k_6 \cdot (T')^2) \quad (3.3)$$

where,

$$I' = \frac{I}{I_{STC}} \text{ and } T' = T_{amb} + (T_{STC}) \quad (3.4)$$

Table 3.1: Characteristic factors for CdTe and pcSi photovoltaic technologies

Parameters	CdTe	pcSi
A, m ²	0.72	1.6368
E STC, W	75.77	235.799
k1	0.0604464	-0.0164826
k2	- 0.028675	-0.0265601
k3	- 0.00186757	-0.00364985
k4	- 0.000318431	-0.000157756
k5	- 0.000084027	-5.46651e-05
k6	- 0.000009734482	-7.94015e-06

with $T_{STC} = 25^{\circ}C$ and light intensity $I_{STC} = 1000W/m^2$. These numbers represent Standard Test Conditions (STC).

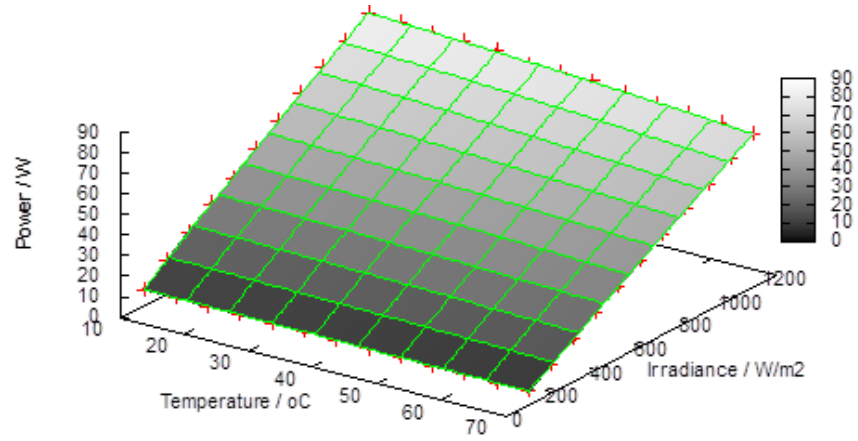
In order to produce the calculations some elements are still should be estimated such as temperature of the module and air temperature at 2 meters above the ground, so called ambient temperature, T_{amb} ($^{\circ}C$).

$$T_{mod} = T_{amb} + (T_{NOST} - 20) \cdot \frac{I}{800} \quad (3.5)$$

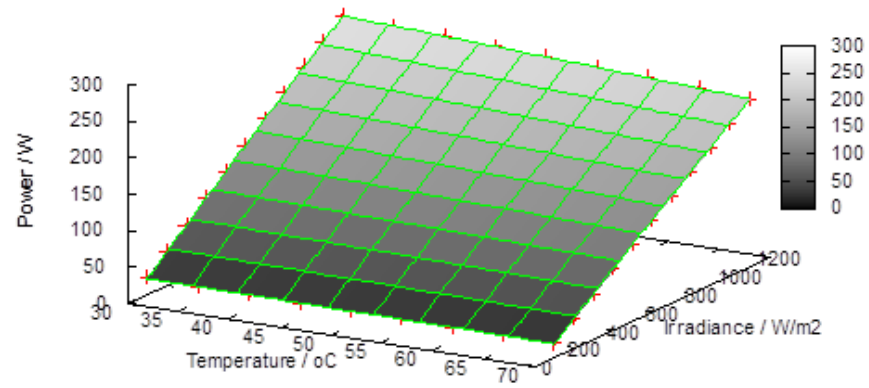
Under the assumption, the nominal operating cell temperature T_{NOST} equals to $45^{\circ}C$ and this value is relevant for both PV technologies, i.e. CdTe and pcSi. Due to the fact that the dataset consists of the information for irradiance during the solar hours and the averages for the months are done according to these intervals, it is crucial to account for average temperature during solar hours too. Therefore, the monthly temperature average can be calculated using the spatially continuous dataset, developed for Europe by the Joint Research Centre (JRC).

The primary temperature dataset with 1-km grid resolution was developed by interpolation of monthly averages of 7 daily values of temperature based on 900 stations between 1995 and 2006. The dataset consists of values for maximum, minimum and measurements for 3 hour intervals from 6:00 to 18:00 hours Greenwich Mean Time (Huld et al. (2006)). The input data represents 5 grid maps for each month. Since the average temperature is non-linear function the calculation of the average temperature profile should be done according to more complicated approach 3.4.

According to the method described by Huld et al. (2006), the average temperature profile can be considered as a curve (or a set of points) representing the typical variation of the temperature within a day for a given location. The average temperature is calculated



(a) CdTe module



(b) pc-Si module

Figure 3.3: Indoor performance matrix for CdTe and pc-Si modules. A performance matrix is built with a series of power measurements at different values of irradiance I , and module temperature T .

according to Huld et al. (2006). An estimate of the average temperature during the daytime can be found by integration (see the equation 3.6):

$$\bar{T} = \frac{1}{t_s - t_r} \int_{t_r}^{t_s} T(t) \partial t \quad (3.6)$$

where t_r is the time of sunrise and t_s is the time of sunset. Therefore the 2nd order polynomial represented by the equation 3.7:

$$\bar{T} = \frac{1}{3} \cdot c_{3,3}(t_s^2 + t_s \cdot t_r + t_r^2) + \frac{1}{2} \cdot c_{2,1}(t_s + t_r) + c_{2,0} \quad (3.7)$$

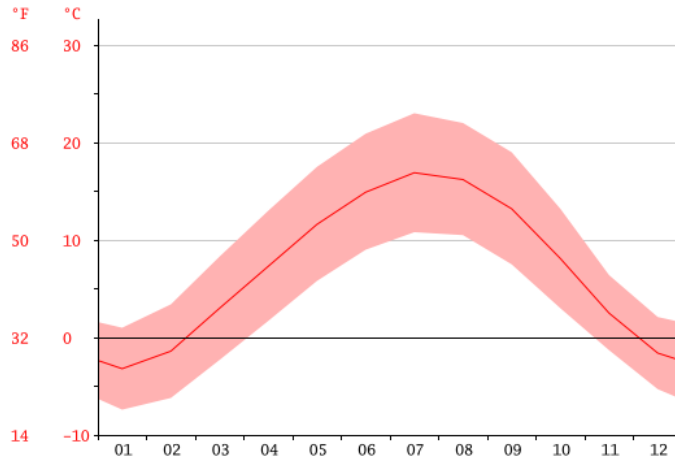


Figure 3.4: Temperature graph. The average temperature is non-linear function the calculation of the average temperature profile should be done according to more complicated approach. Therefore the average temperature profile can be considered as a curve representing the typical variation of the temperature within a day during a month for a given location. The figure from <http://en.climate-data.org/location/54150/>

while the 3rd order polynomial can be seen at the equation 3.8:

$$\bar{T} = \frac{1}{4} \cdot c_{3,3}(t_s^3 + t_r^3 + t_r \cdot t_s^2 + t_s \cdot t_r^2) + \frac{1}{3}c_{3,2}(t_s^2 + t_s \cdot t_r + t_r^2) + \frac{1}{2} \cdot c_{3,1}(t_s + t_r) + c_{3,0} \quad (3.8)$$

The local solar sunrise t_r and sunset t_s times can be calculated as it is seen at the equations 3.9 and 3.10:

$$t_r = 12 - \frac{12}{\pi} \arccos \left(-\frac{\sin \phi \cdot \sin \delta}{\cos \phi \cdot \cos \delta} \right) \quad (3.9)$$

$$t_s = 24 - t_r \quad (3.10)$$

Where ϕ is the geographical latitude and δ is the declination of the day in the year. The formula is not valid in polar regions during periods when the sun does not rise or does not set. In these cases the calculated day length will be less than 0 or greater than 24 hours (Huld et al. (2006)). However, for the purposes of the following research the solar sunrise t_r and sunset t_s times were taken approximate for the typical day of a month.

In order to estimate the averages temperature it is necessary to produce regression analysis on a series of temperature datasets based on curve fit of 3rd order polynomial. Therefore, the time during the day is set of first variables, which paired with the temperature

values. Furthermore, the function of curve fit uses nonlinear regression technique to calculate a unique mathematical model at each pixel of the input raster datasets. The output of the curve fit is the raster data with averaged temperature values during the solar time. Curve estimation gives the model of prediction and explanation temperature values during the typical day of a month. In the figure 3.5 the averaged temperature during the typical year can be seen. The yearly temperature will be used for the model assessment, although the temperature for each month is estimated and stored in the database as well and will be used for the future development.

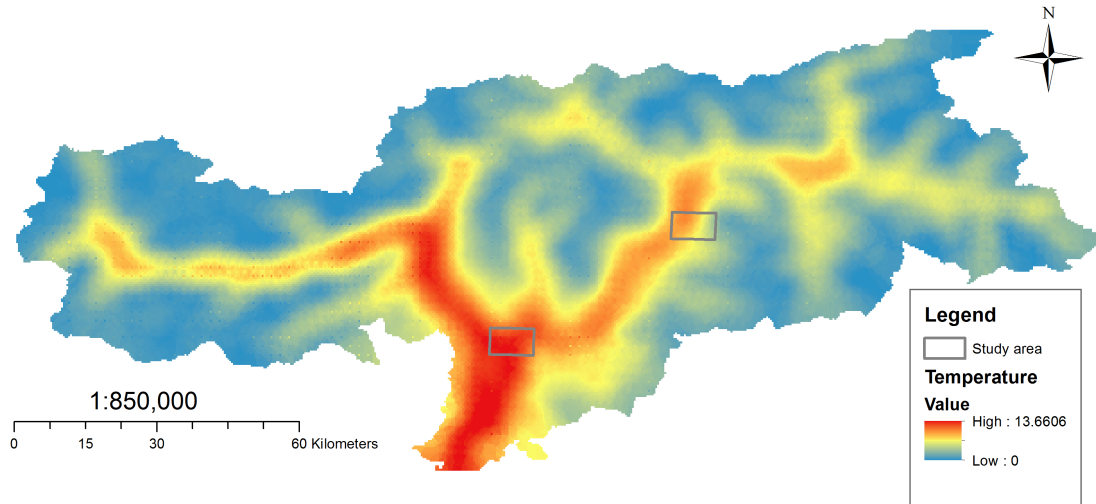


Figure 3.5: Average profile of daily ambient temperature during a year. The estimation is produced by applying regression analysis based on the data from spatially-continuous dataset with 1-km grid resolution that was developed by interpolation of monthly averages of 7 daily values of temperature: minimum and maximum and 5 measurements at 3-h intervals from 6:00 to 18:00 hours Greenwich Mean Time.

In order to evaluate the electrical potential energy E_{pv} (kWh/m^2), the temporal resolution should be taken into account (see the equation 3.11)

$$E_{pv} = P_{pv} \cdot D \cdot H \cdot \frac{1}{1000} \quad (3.11)$$

Where D is number of days in a month and H is number of solar hours during the day.

The nominal power P_{STC} of a photovoltaic system can be measured in kWh/kWp . It is the power output, which is very important characteristic for the technical planning of installations. To estimate this parameter the electrical potential energy E_{pv} along with a module size that can produce the power of 1 kWp for a particular technology should be considered. CdTe and pcSi have cell efficiency about 10 and 14 percents respectively.

Strictly speaking, in order to produce the results of very high quality, the estimations of electrical energy and electrical power should be done for each interval of time that was used during the computation of total daily radiant energy. Although it can afflict the performance of WebGIS. In the future development the additional coefficient might be applied to reduce the uncertainty.

Besides, the emissions savings are an important parameter for evaluation of the photovoltaic systems. Even though it can be calculated with very complex formula, which is out of scope of the following work, the approximate results can be achieved by applying an particular coefficient on electrical energy E_{pv} , which is equal to 0.5 for South Tyrol, Italy.

Furthermore, ventilation is an important factor to consider when a PV system is designed. High temperature of a module could decrease the efficiency of the system. Based on the Gargallo (2011) the conductivity of a semiconductor increases when the temperature is higher, therefore it is easier for electrons to holes elsewhere in the material to fill, being the electrical balance in the cell increases, the electric field falls away to the boundary, so the load can no longer remain well separated. The result is a decreasing tension between the two layers. Consequently, it is of paramount importance to keep the module as cool as possible by providing natural ventilation. This effect can be seen in the figure 3.6.

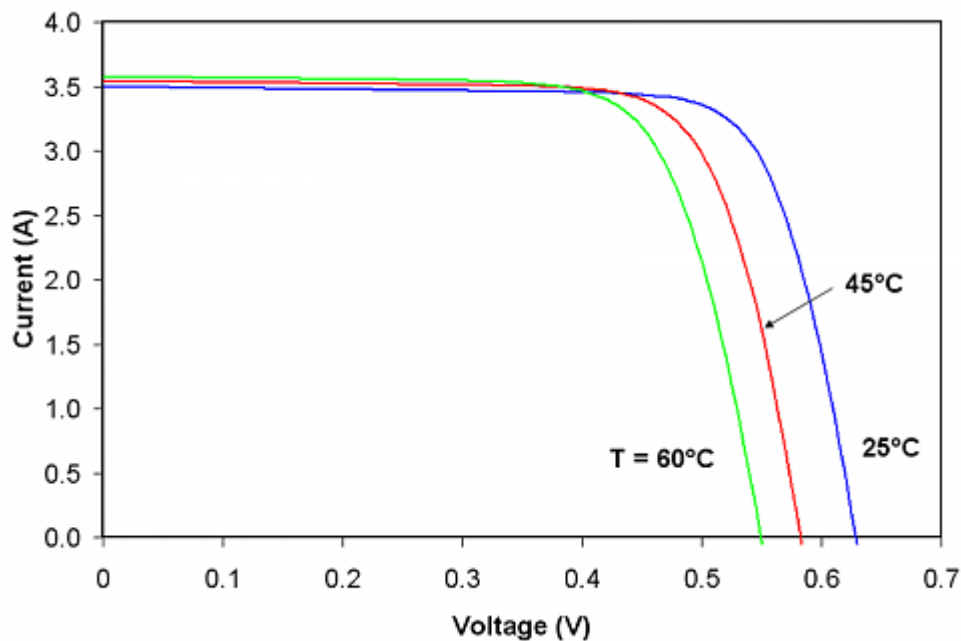


Figure 3.6: Effect of temperature on voltage. The photovoltaic system could have losses due to high temperature, therefore it is important to keep the system as cool as possible. The figure from Gargallo (2011)

The ventilation factor could be adjusted considering different module temperatures (see the equation 3.5). Therefore, the ventilation is characterised by the following coefficients:

- Well-ventilated system:

$$\frac{T_{NOST} - 20}{800} = 0.03125; \quad (3.12)$$

- Poorly ventilated system:

$$\frac{T_{NOST} - 20}{800} = 0.035; \quad (3.13)$$

- Non ventilated system:

$$\frac{T_{NOST} - 20}{800} = 0.04; \quad (3.14)$$

When it comes to the estimation of the solar potential for producing domestic hot water, it should be done considering a great number of different components. Therefore the estimation of solar thermal potential is a complicated task which could not be fulfilled just by knowing the incoming radiation and average temperature. Kalogirou (2004) claims that the proper sizing of the components of a solar system is a complex problem which includes both predictable (collector and other components performance characteristics) and unpredictable (weather data) components. In order to estimate the solar thermal potential, the large number of components should be taken into account as number of storey, number of people, building plan, application of the building, slope, orientation and domestic water consumption. It can happen that roofs which are suitable for PV are not suitable for the solar hot water systems, therefore there is no compromise between these two systems. It is of paramount importance to know the building classification, since the thermal potential estimation is strongly based on the application of the building (industrial, private, hotels). For example a residential building is consuming different amount of water than an industrial building. For all these reasons the current WebGIS application doesn't take into account the estimation of the thermal potential, since it can be done only roughly, and that will reflect unreliable information.

Roof surface extraction from DSM

Apparently, the radiation data should be represented on the surface that can provide with potential characteristics on a particular area. Therefore, the roof surfaces should be extracted from raster format as vectore features. Further, these features should be assign to cadastre tiles, therefore the informaton is structured according to an official breakdown. Generally, 3D roof facets extraction from DSM data involves several basic methods and techniques such as image segmentation and classification (Sampath and Shan (2010)). Image segmentation is the process of partitioning an image into meaningful regions. Regions

can be foreground versus background or individual objects in the image. The regions are constructed using some feature such as color, edges, or neighbor similarity. The task of roof surfaces is quite complex due to regions on the roof such as breaklines and small chimneys which are considered its “non-planar” parts.

Nevertheless, the radiation data should be visualized with high level of details, therefore it makes sense to extract not only building polygons, but each roof facets, since incoming solar radiation hitting the roofs with different intensity depending on shadows, orientation, slope and aspect. Consequently, in order to show the comprehensive level of information it is essential to have detailed information about the roof surface. According to Brenner (2000), the figure 3.7 shows the results of several segmentation algorithms for a laser scanner DSM with a ground resolution of one meter. Hence, based on these methods roof surfaces could be distinguished into several polygons depending on the geometry of a roof. The figure 3.7a shows segmentation into regions which have normal vectors compatible to the ground plan, and figure 3.7b shows a segmentation based on contours. Finally, the figure 3.7c shows a RANSAC-based segmentation into planar regions (Brenner (2000)).

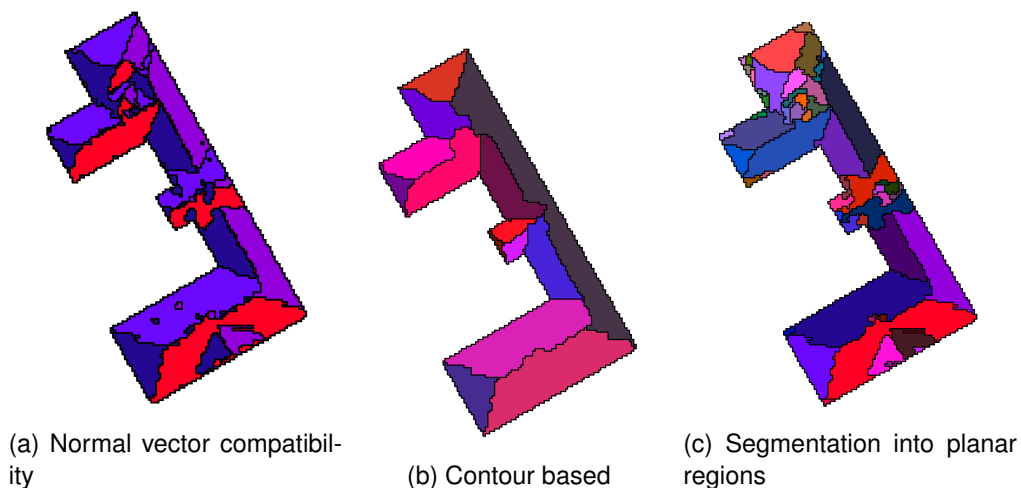


Figure 3.7: Results of several DSM segmentation algorithms. The figure shows the results of several segmentation algorithms for a laser scanner DSM with a ground resolution of one meter. The figure 3.7a shows a segmentation into regions which have normal vectors compatible to the ground plan, and figure 3.7b shows a segmentation based on contours. Finally, the figure 3.7c shows a RANSAC-based segmentation into planar regions (Brenner (2000))

Generally speaking, based on Brenner (2000), the RANSAC-based approach (see the figure 3.7c) generates more planar regions than the other two algorithms such as normal vector compatibility and contour based segmentation. Even though the polygons could be aggregated into bigger entities by applying different aggregation functions, which of course

increase the computational effort.

As far as contour based segmentation (see the figure 3.7b) is concerned, it starts with detection of the edges of the image and then it goes on with linking process that seeks for continuity. Based on Leung and Malik (1998), the major advantage of contour-based approaches is that the grouping factor of curvilinear continuity can be treated very naturally. However, there are some disadvantages, as for instance the contour-based techniques do not give closed connected regions. Besides, to detect an extended contour of very low contrast, a very low threshold has to be set for the edge detector. This will cause random edge segments being found everywhere in the image.

As regards, the normal vector compatibility (see the figure 3.7a) it uses three components of the normal vector to define a plane. By means of these attributes the vector can partition the associated points into distinct regions (Abdul-Rahman et al. (2006)). However, there is an ambiguity of parallel planes can occur, they will be distinguished into the same feature. Nonetheless, this is not an issue in the following work, since the polygons will be further aggregated according to the cadastre data.

Although, these methods give different benefits and drawbacks. Therefore, in the following study it was decided to use the segmentation by the normal vector, since it shows the sub-surfaces according to the geometrical properties and it gives an acceptable level of details.

As it has been mentioned, the sub-surfaces are intersected with the cadastre data, that makes it possible to identify an affiliation of each sub-surface polygon to a particular cadastre entity. Besides, the normal vector segmentation creates bigger polygons than RANSAC-based approach, therefore it is more suitable for the current research since the minimum aggregation effort could be performed.

3.2 Design and Implementation

The use of interactive maps brings a lot of opportunities to visualize all sort of data on a digital map that is presented in convenient and interactive way. Nonetheless, to design and implement the application the technical and user requirements should be set. Besides, the convenient and successful analysis of large amount of spatial data for a research requires an adequate storage, retrieval, integration and visualization of the data. Therefore, the data should be well-organised with possibility to use the it in different formats including vector and raster, perform query operations and spatial analysis.

Based on the methodology for solar potential estimation the data should be organised in a spatial database, hence it can be easily manipulated, retrieved and related to all other data stored in the database. Consequently, the data models are of paramount importance since

they can help to identify the factors affecting the photovoltaic production, reflect the inputs and outcomes and show the dependencies among the variables. Besides, the development of logical model can directly assist in the database design. Based on the database models, the processing chain of the application should be established in a way that can satisfy the estimations on-the-fly. To do so the application should contain the appropriate architecture including database management, application and client sides. The detailed description of the WebGIS architecture could be found in the chapter 5.2. The three-tier architecture model is the fundamental framework for the logical design model. It segments an application's components into three tiers of the services. The services are illustrated in the figure 3.8:

- User interface is incorporated in Web Browser and the implementation of the layout and interaction is done in JavaScript, JSP and CSS;
- An application server is a component uses Apache as Web Server and Apache Tomcat as Servlet Engine. On the Servlet Engine there are running two servlet containers: Geoserver 3.9 and the other is responsible for the configurations of the WebGIS;
- A data layer comprises the access to file data sets (raster or vector) and to a DBMS. In the actual research the open-source Object-Relational DBMS PostgreSQL(see the figure 3.10) and its extension for the spatial data is used.

The client communicates with the Web Server via the Internet HTTP protocols. Therefore, the content is exchanged using standardized OGC service (Web Map Service (WMS), Web Map Tile Service (WMTS) and Web Feature Service (WFS)). The exchange format is Extensible Markup Language (XML) and JavaScript Object Notation (JSON) for textual content and SVG, PNG or JPG for binary content (images).

As it was defined at OGC (a) The WFS represents a change in the way geographic information is created, modified and exchanged on the Internet. The WFS offers direct access to geographic information at the feature and feature property level. The WFSs allow clients to retrieve or modify the data they are seeking, rather than retrieving a file that contains the data. Therefore, the data can be used then for a wide variety of objectives.

Based on OGC (b), a WMS produces maps of spatially referenced data dynamically from geographic information. Moreover, it is pointed out that WMS-produced maps are generally rendered in a pictorial format such as PNG, GIF or JPEG, or occasionally as vector-based graphical elements in Scalable Vector Graphics (SVG) or Web Computer Graphics Metafile (WebCGM) formats.

According to OGC (c) WMTS Implementation Standard provides a standard based solution to serve digital maps using predefined image tiles. The service advertises the tiles it has available through a standardized declaration in the ServiceMetadata document common to all OGC web services.

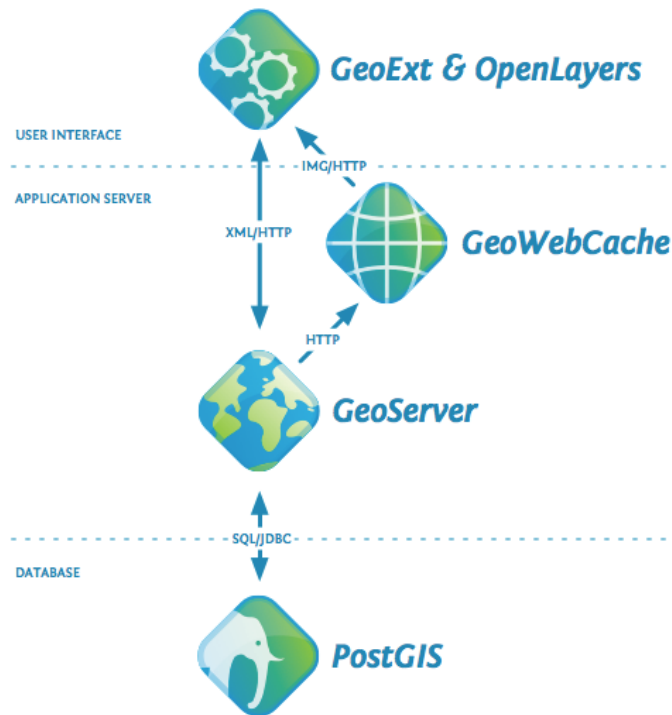


Figure 3.8: WebGIS architecture in action. The key to the architecture is breaking Internet mapping into functional layers. The picture is from OpenGeo Suite.

The screenshot shows the GeoServer web interface. The top navigation bar includes the GeoServer logo, a user status indicator ("Logged in as admin."), and a "Logout" button. The left sidebar contains a menu with sections: "About & Status", "Data", "Services", "Settings", and "Tile Caching". The main content area is titled "Layers" and contains a table of published layers.

Type	Workspace	Store	Layer Name	Enabled?	Native SRS
<input type="checkbox"/>	nurc	arcGridSample	Arc_Sample	✓	EPSG:4326
<input type="checkbox"/>	nurc	img_sample2	PK50095	⚠	EPSG:32633
<input type="checkbox"/>	nurc	mosaic	mosaic	✓	EPSG:4326
<input type="checkbox"/>	nurc	worldImageSample	Img_Sample	✓	EPSG:4326
<input type="checkbox"/>	sf	sf	archsites	✓	EPSG:26713
<input type="checkbox"/>	sf	sf	bugsites	✓	EPSG:26713
<input type="checkbox"/>	sf	sf	restricted	✓	EPSG:26713
<input type="checkbox"/>	sf	sf	roads	✓	EPSG:26713
<input type="checkbox"/>	sf	sf	streams	✓	EPSG:26713
<input type="checkbox"/>	sf	sfdem	sfdem	✓	EPSG:26713
<input type="checkbox"/>	solarlyrol	solarlyrol	irradiance	✓	EPSG:32632
<input type="checkbox"/>	solarlyrol	solarlyrol	pv_buildings_plot	✓	EPSG:32632
<input type="checkbox"/>	solarlyrol	solarlyrol	pv_monuments_plot	✓	EPSG:32632
<input type="checkbox"/>	tiger	nyc	giant_polygon	✓	EPSG:4326
<input type="checkbox"/>	tiger	nyc	poi	✓	EPSG:4326

Figure 3.9: GeoServer is an open source server for sharing geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards.

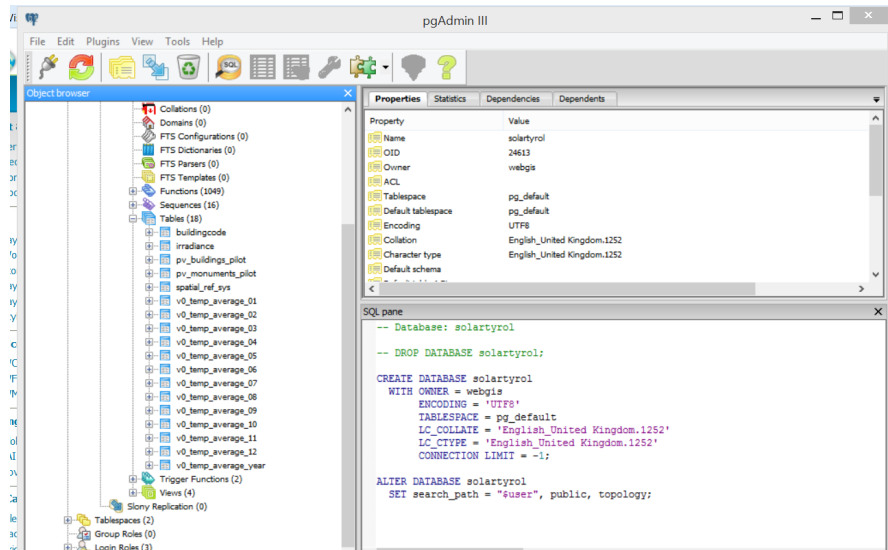


Figure 3.10: PostgreSQL object-relational database and its extension for spatial data PostGIS that adds support for geographic objects allowing location queries to be run in SQL.

Moreover, the solar potential data and its metadata should be available to the wide audience of private users, authorities and companies. Due to the fact that the project was organized with support of Autonomous Province of Bolzano, the information should be shared via the portal of the Province as well by means of Web services and metadata harvesting. For this reason it is essential to take into account the SDI implementation to support the storing, retrieval and managing of the spatial data. As reported by Kuhn (2005), an SDI is a coordinated series of agreements on technology standards, institutional arrangements, and policies that enable the discovery and use of geospatial information by users and for purposes other than those it was created for. According to Giuliani et al. (2011), SDIs are being widely used in the environmental sciences to share, discover, visualize and retrieve geospatial data through OGC Web services.

Steiniger and Hunter (2012a) analyzed the GIS software and the major software components that exist in a general SDI architecture and concluded it in the following groups (see also figure 3.11).

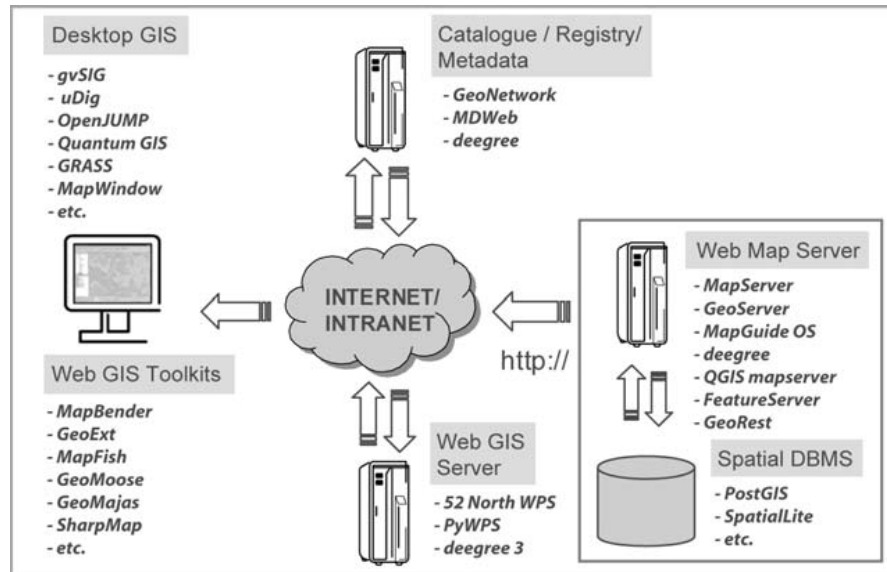


Figure 3.11: SDI architecture

- SDI server software: Web map servers, server GIS;
- SDI spatial data storage: Spatial DBMS;
- SDI registry/catalogue and metadata software;
- SDI client software: desktop GIS clients, Web-GIS development toolkits.

In order to support the application layer, the following software components were used: GeoServer, Apache TomCat and Apache. The design of Geoserver 2.5, an open source server for sharing geospatial data, allows interoperability, because it publishes data from any major spatial data source using open standards. Furthermore, free-based spatial DBMS PostgreSQL 9.2 and its extension PostGIS 2.0 were used. PostgreSQL is the advanced, open-source object-relational DBMS of standards-compliant and extensible philosophy. The SDI Registry is represented by Geonetwork EURAC, a spatial catalog developed within the group of Technology for Environmental Monitoring, Institute for Applied Remote Sensing, EURAC Research.

As regards the development toolkits, OpenLayers Java library is the basis of the application. Hazzard (2011) indicates that OpenLayers is a powerful, community driven, open source, pure JavaScript web-mapping library. It provides with the facility to create rich mapping application using WMS, Base Layers, namely GoogleMaps, Bing Map and OpenStreet Maps. Moreover, Ext.js 3.4 is a pure JavaScript application framework that delivers the components for the user interface. Ext.js 3.4 is supported by all the main browsers. The framework GeoExt.js 1.1 contains the components and data utility classes that extend map related

functionality to equivalent classes in Ext.js. Therefore, based on User Manual GeoServer 2.5.x (2014) an interoperability among the tools is explained on the figure 3.8.

To sum up, the architecture of a WebGIS application could be presented as following:

- Storage: PostgreSQL, PostGIS. The data should be stored in a DBMS.
- Application server: Geoserver. The raw data needs to be accessed and rendered using Web services.
- Application cache: To gain better performance the data could be cached of as map files.
- User interface framework: GeoExt.js, Ext.js.
- User interface map component: JavaScript Web Mapping framework OpenLayers, Google Maps API, Bing Maps API, Open Street Map API.

3.3 Evaluation of Results

Solar Tirol WebGIS is a new application, therefore it is still being developed, and apparently, the application should be enhanced based on the feedback of the quality, usability and the social benefits. There are several approaches to demonstrate the usability, advantages and to reveal drawbacks. First and foremost, the usability could be tested based on very a complex methodology which applies a selection of participants and it requires to achieve desired levels of thoroughness or benefits. However, there are some disadvantages of such usability testing, especially when it is done at the beginning of the development. First of all, testing is not fully representative of the real life scenario, as for example if the participants are selected among random casual people it can happen that in a real life they would never use such kind of tool simply because they are not interested in the topic. From another hand, people who have an idea about, in case of actual research, photovoltaic, they would search for the information and could give a valuable feedback. Besides, the usability testing is mainly qualitative, therefore it does not provide the large samples of feedback that a questionnaire might do. Along with it, another solution could be a tool which allows the users leave their questions, feedbacks, and recommendations for the future development in a form of communication between a user and developer. As for example Ext.js is providing an example of a common “Contact us” form (as it is illustrated on the figure 3.12) that could be extended with other questions and included into the application.

As regards the usability questionnaire, this option is very useful in the beginning of the development, since it can give valuable feedback and help to evaluate the application according to expert opinion and bring forward new improvements. Due to the fact that the application is in the testing regime, the participants were found among the employees from

The image shows a standard web form titled "Contact Us" in a light blue window. The form contains the following elements:

- Your Name:** Three input fields labeled "First:", "MI:", and "Last:".
- Your Email Address:** A single-line text input field.
- Subject:** A single-line text input field.
- Message:** A large multi-line text area.
- Buttons:** "Cancel" and "Send" buttons at the bottom right.

Figure 3.12: "Contact us" form provided by Ext.js. Such form could be extended with other questions and give the possibility for communication between a user and a developer which can bring forward new improvements.

the Institute for Remote Sensing and Institute for Renewable Energy involved in the work with photovoltaic assessment that volunteered their time for answering some questions regarding the work of the application and user interface design.

To evaluate the overview of the application the users could be asked to look through the application, read carefully the introduction, used approach, assumptions and instructions of how to use. Furthermore, the user should test the main features, navigate the map, request the information about a roof, test the layers and available tools. The next assignment could be related to gathering the information about the datasets and investigating their metadata. Each assignment should be evaluated, therefore it can be seen if the user face any problems using the WebGIS. Afterwards, the following questions should be addressed:

- Would you use the WebGIS if you planed the installation of the solar system in your own house?
- Could you acquire all the needed information about the solar potential from the WebGIS?
- Is there missed information?
- Are you aware of the constraints in the solar potential estimations?
- Do you find the application user-friendly?
- Are you interested in the information about the dataset?
- Are you satisfied with the user-experience?

Besides, the testers should be asked to report the problems and suggestions. The user survey and its results are available in Appendix C.

Chapter 4

Data Model and Database Design

The convenient and successful analysis of large amount of spatial data for a research requires an adequate storage, retrieval, integration and visualization of the data. Based on Winstanley (2009) spatial databases are designed specifically to include data with spatial attributes, such as geographical location, distance, and extent. Furthermore, the software used to manage and query a database that is known as Database Management System (DBMS). As it was identified by Greener and Ravada (2013) a spatial DBMS mainly includes:

- support of different data formats including vector and raster formats,
- spatial indexing mechanism for faster querying and retrieval,
- operators, functions and procedures for performing spatial analysis and query operations,
- persistent topology data model for working with data about nodes, edges, and surfaces in a topology,
- a network data model,
- raster data type support that lets store, index, query, analyze and deliver raster data.

Once the data is stored in spatial database it can be easily manipulated, retrieved and related to all other data stored in the database. Moreover, due to the fact the WebGIS application is based on the different kind of data, it should be synchronised in a way that allows to identify the dependencies among the elements. Therefore, the development of a relational database structure is of paramount importance.

In order to describe the factors influencing on solar panels and the process of solar potential estimation the conceptual models were developed. Whereas the logical model was made to represent the geospatial data structure. The processed solar radiation and cadastre data are stored in a PostgreSQL object-relational database with the support of the PostGIS library for geographic objects. Hence, this chapter discusses the SDI components,

data sources, data models and key components of the database design for the Web-based solar cadastre.

4.1 Spatial Data Infrastructure for Support of Solar Radiation Data

In order to realise the WebGIS development it is advisable to establish SDI that can provide potential users an access to stored spatial data and assist in the sharing of data, saving resources, time and effort by reducing duplication of the information and effort for its support. Therefore, the data could be found from a repository via Web services. As reported by Kuhn (2005), an SDI is a coordinated series of agreements on technology standards, institutional arrangements, and policies that enable the discovery and use of geospatial information by users and for purposes other than those it was created for. According to Giuliani et al. (2011), SDIs are being widely used in the environmental sciences to share, discover, visualize and retrieve geospatial data through OGC Web services.

According to Steiniger and Hunter (2012b) the basic software components of an SDI consists of:

- a software client that can display, query, and analyse spatial data,
- a catalogue service for the discovery, browsing, and querying of metadata or spatial services, spatial datasets and other resources,
- a spatial data service that enables the delivery of the data via the Internet, and/or processing services such as datum and projection transformations,
- a (spatial) data repository,
- GIS software (client or desktop) that permits the creation and maintenance of data.

The WebGIS Solar Tirol has been developed based on SDI components provided by EURAC research. As it can be seen from the table 4.1, it has all the elements to fulfill the needs of comprehensive access to the information.

4.2 Data sources

The initial data, the DTM and DSM, was derived from the LIDAR data and provided within the project “Solar Tirol” as input information for the further estimations. The resolutions of the models are 0.5 m for the main valleys and 25 m for the other regions. Based on it, the responsible party provided with the insolation data estimated for every hour during the solar time each day. In addition the monthly averaged sums are calculated, consequently for the

Table 4.1: EURAC SDI components

SDI component	Technology	Purpose
Catalogue	GeoNetwork	Spatial catalog to handle the information about the data
SDI Server software	GeoServer, Apache Maven	GIS Server for publishing OGC Web services; Java Library used to run built in tasks
Development toolkits	OpenLayers library 2.0, Ext 3.4, GeoExt 1.1, Google libraries	2D Visualization/Rich WebGIS GUI
Spatial DBMS	PostgreSQL, PostGIS	Database Server with Spatial Extension
Client software	QGIS, GRASS GIS	Data processing

further work the twelve raster datasets are used. Furthermore, the data preprocessing is performed that includes an intersection and aggregation of the data. Therefore, in order to create a dataset that could include the insolation information from the raster data (R) and vector-based (V) roof facets, two types of data should be intersected in a way that each vector polygon could inherit the radiation values as a statistic function of mean value (see the equation 4.1). The data samples are illustrated on the figure 4.1

$$\text{Insolation \& Roof facets (V)} = \text{Insolation (R)} \cap \text{Roof facets (V)} \quad (4.1)$$

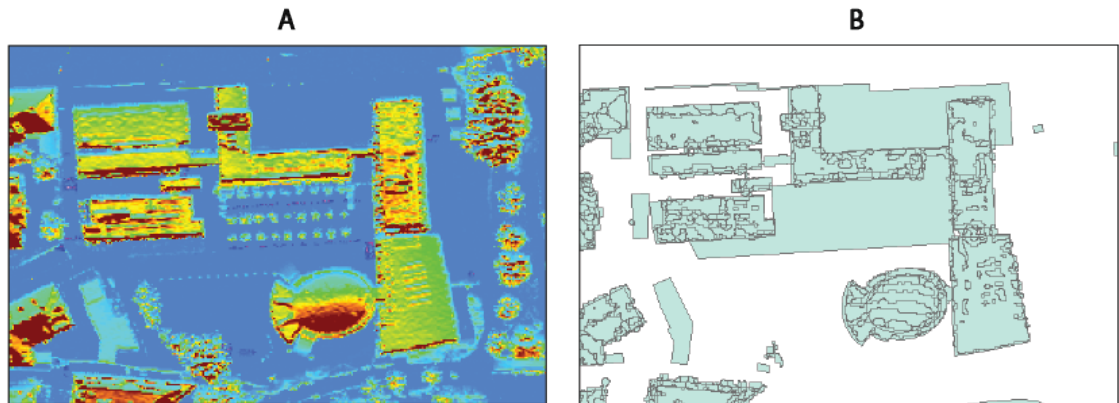


Figure 4.1: Spatial intersection of (A) insolation (raster) data and vector-based (B) roof facets. To provide with the compact and easy-to-handle data, the spatial intersection between the radiation data and sub-surface vector data was performed. Based on this procedure the sub-roofs got additional attributes that contain the information about mean insolation within a polygon.

The intersection operation is performed using the Geospatial Modelling Environment (GME). It is a platform designed to help to facilitate rigorous spatial analysis and modelling. Strictly speaking, the tool performs the intersection of polygons with raster, and creates summaries for each polygon based on the values in a raster layer.

Example:

```
isectpolyst((in= C:\data\roof_facets.shp ,
raster= C:\data\insolation.tif ,
prefix= IR01MN , MEAN);
```

This tool summarizes the raster cell values that are contained by a polygon. As for example, the raster layer has insolation values $A = (AA)$ and the vector layer has the values $B = (BB, CC, DD, EE, \dots)$ (see the equation 4.2).

$$C(AA, BB, CC, DD, EE) = A(AA) \cap B(BB, CC, DD, EE) \quad (4.2)$$

The output consists of summary fields that are added to the polygon attribute table: $C = (AA, BB, CC, DD, EE)$. Based on Beyer (2014), for continuous rasters a statistical summary is produced (the mean, median, minimum, maximum, standard deviation, count). Polygons are processed sequentially, so are not affected in any way by overlapping polygons. NoData cells are ignored. Therefore, if the polygon contains NoData cells this may influence the accuracy of the statistical summary. By default, any polygons that are entirely or partially outside of the extent of the raster will not be processed - they will be coded with NoData values (-2147483648) so should be easily identifiable (Beyer (2014)).

Afterwards, the resulting dataset $C(AA, BB, CC, DD, EE)$ is combined with the cadastre data $D(FF, GG)$ (see the equation 4.3), since it can eliminate the unnecessary radiation data that go beyond the building roofs. Moreover the data was generalized in order to reduce the complexity and eliminate small features.

$$E(AA, BB, CC, DD, EE, FF, GG) = C(AA, BB, CC, DD, EE) \cup D(FF, GG) \quad (4.3)$$

In order to produce the estimations for solar potential characteristics the ambient temperature data is necessary too. The temperature was estimated according to the established methodology (chapter 3.2). The regression analysis was produced on a series of temperature datasets. Therefore, the time during the day is set of first variables, which paired with the temperature values. Furthermore, the function of curve fit uses nonlinear regression technique to calculate a unique mathematical model at each pixel of the input raster datasets. The output of the curve fit is the raster data with averaged temperature values during the solar time. Curve estimation gives the model of prediction and explanation temperature values during the typical day of a month. Hence, the yearly average could be estimated based on

the monthly values (see the figure 4.2) The yearly temperature (see the figure 3.5) is used for the model assessment.

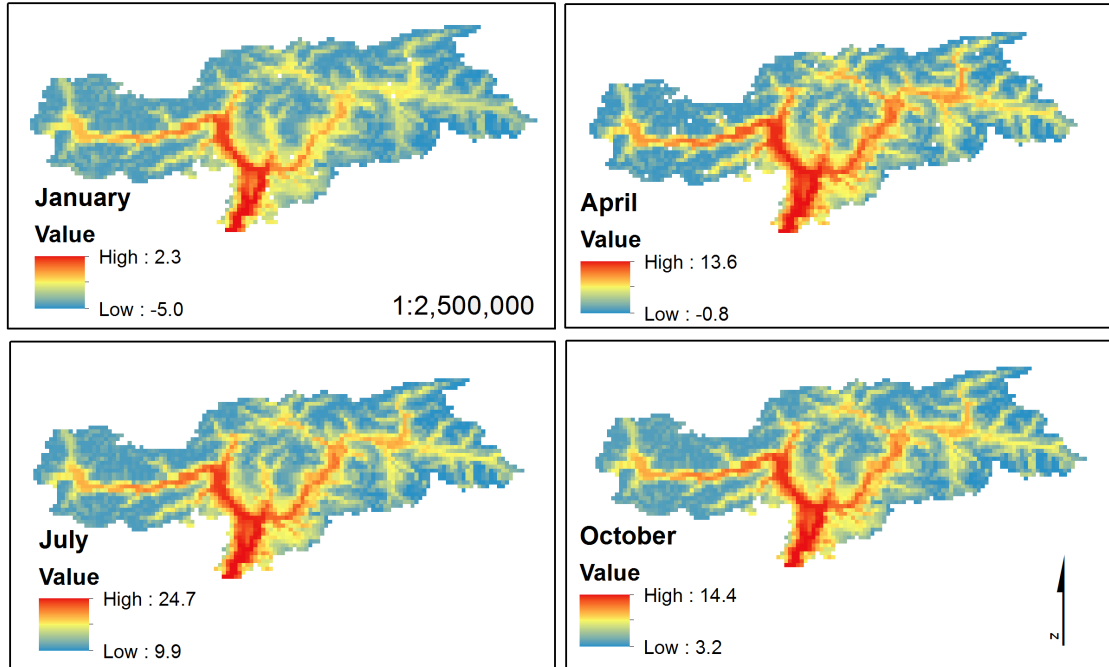


Figure 4.2: Average monthly temperature. In total 12 rasters. The regression analysis was produced on a series of temperature datasets. The output of the curve fit is the raster data with averaged temperature values during the solar time. Curve estimation gives the model of prediction and explanation temperature values during the typical day of a month.

The table 4.2 represents the overview of the used data.

Apparently, there are three major data sources. First of all, it is insolation received by surface for each month of the year for the particular location of interest measured in Wh/m^2 . The insolation should be converted into irradiance by considering the number of solar hours during a day and number of days during a months. The estimation of the insolation should include the correction factors as cloud correction and Linke turbidity correction. However, as it was mentioned before, under the scope of the following work the cloud correction is not considered, due to absence of available and trustful information. Nonetheless, the cloud correction could be provided within the future development and it can be added to the algorithm without changing the approach. Secondly, it is the temperature data for the study area. Last but not least, cadastre data is crucial for detection of building structures.

Table 4.2: Data sources

Layer	Data type	Description
DTM, DSM	Raster	The grid with spatial resolution of 0.5 m and 25 m for main valleys and mountain regions respectively.
Insolation	Raster	Mean of daily insolation received by the surface for each month of the year measured in Wh/m^2 .
Roof facets	Vector	The polygons are extracted from the DSM by segmentation into regions which have normal vectors compatible to the ground plan.
Insolation & Roof facets	Vector	The polygons are the product of intersection between the insolation data and roof facets. Furthermore, the data was aggregated according cadastre attachment and generalized.
Temperature	Raster	The grid with spatial resolution of 1 km was derived by spatial interpolation of monthly-averaged daily values of temperature - minimum/maximum and 5 measurements at three-hour interval from 6:00 to 18:00 GMT.
Cadaster Parcels	Vector	Cadaster parcels information. Building footprints are based on the cadaster information. The layer reflects the shape of the basements. In some cases it includes backyards as well.
Protected areas	Vector	Areas included in the list of monuments, architectural heritage or public buildings

4.3 Conceptual Data Model

A conceptional model is a simplified representation of the real world that shows its components in an abstracted way. According to John (2003), the conceptual model is a key element in understanding the natural processes. It reflects the system elements and can show the trends, therefore the conceptual models and diagrams are widely used to retrieve the interactions between components and dependencies within the system (John (2003)). In order to identify the factors affecting the photovoltaic production a conceptual model (see the figure 4.3) was developed.

The figure 4.4 reflects the inputs and outcomes and shows the dependencies among the variables. As it can be seen, there are some constant parameters, that are characteristics of a PV technology and constant values derived from the empirical studies. Analysing the models, several conclusions can be made. First of all, the amount of incoming radiation is strongly depended on the geographical location, temperature, time and obstructions. Hence,

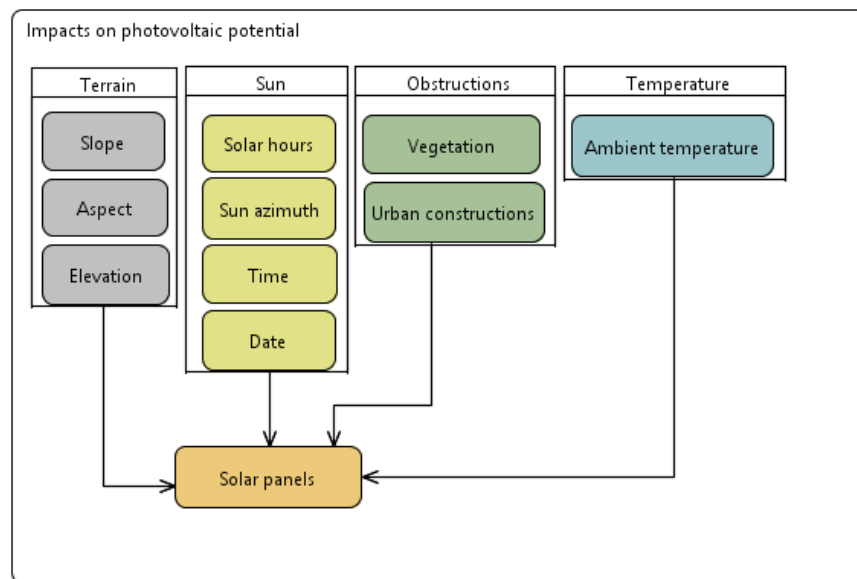


Figure 4.3: Factors affecting photovoltaic production. The amount of incoming radiation is strongly depended on the geographical location, temperature, time and obstructions. Hence, the models illustrates the main components that are considered within the solar potential estimations: temperature, incoming radiation and time.

the models illustrates the main components that are considered within the solar potential estimations: temperature, incoming radiation and time. As shown in the figure 4.4, the database can contain only radiation data, temperature and cadastre information, therefore the rest of the information can be estimated.

4.4 Logical Data Model

The Unified Modelling Language (UML) is a graphical language for communicating specifications during the process of the software design. UML has grown into a standard of the design of digital systems in general (Teorey et al. (2005)). Therefore, the geospatial databases could be described as UML diagrams as well, since classes and objects are a natural way of conceptualizing the world around us. In the following work the UML schema (see the figure 4.5) presents the ideal case for the development and consists of some classes and attributes which are not covered in the following work, but the development of the WebGIS application will be continued, that is why it was essential to include them.

Therefore, in accordance with the developed schema the database was created under a support of free-based software, namely PostgreSQL, PostGIS and GDAL library. The figure 4.6 illustrates the database structure.

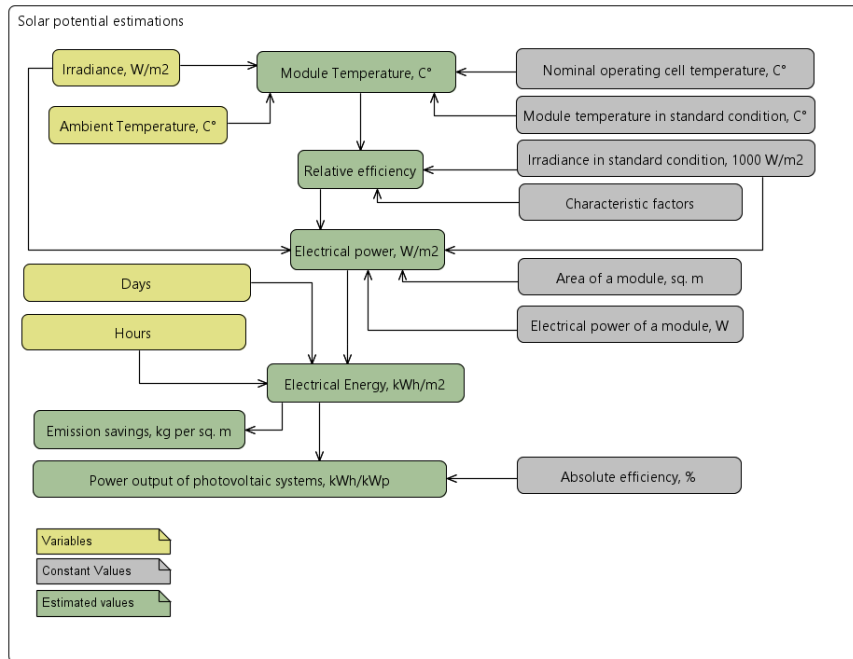


Figure 4.4: Estimation of solar potential. The database can contain only radiation data, temperature and cadastre information, therefore the rest of the information can be estimated

4.5 Data storage and integration

The provided input data is of heterogeneous type, therefore it should be facilitated in a convenient way. For this reason an integrated environment was used that can provide the data management and data extraction. In order to store, modify and extract the information free-based Database Management System was chosen, namely PostgreSQL 9.2 server with its extension PostGIS 2.1.1. PostgreSQL is an Object-Relational DBMS developed at the University of California at Berkeley Computer Science Department (Group (2014)). The use of DBMS provides the possibility for analysis and spatial queries within the database. What's more, the support for rasters in the PostGIS spatial database is a relatively new feature, which lets integrate the raster data as PostGIS GEOMETRY type. As for instance, in the following research the temperature raster dataset is stored in the database and it is not visualized within the user interface, therefore the PostGIS query is used to request the raster values on the selected location. Besides, it is the way easier to maintain the database rather than a set of separate files, therefore all the updates could be made within one system. As regards the projections, the PostGIS could take care of them as well. For example, the temperature raster data has different projection, therefore the temperature value is requested and transformed into the projection of the remaining data as it can be seen from the expres-

public	
public.pv_buildings_pilot	
gid	integer « pk nn »
feature_id	integer
datum	date
ort_id	integer
shape_leng	numeric
shape_area	numeric
height	double precision
height_rel	double precision
objectid	numeric(10,0)
build_it	character varying(100)
build_de	character varying(100)
build_en	character varying(100)
heightstr	character varying(10)
height_rst	character varying(10)
geom	geometry(MULTIPOLYGONZM, 32632)
pv_buildings_pilot_geom_gist index	
public.irradiance	
gid	integer « pk nn »
ir01mn	numeric
ir02mn	numeric
ir03mn	numeric
ir04mn	numeric
ir05mn	numeric
ir06mn	numeric
ir07mn	numeric
ir08mn	numeric
ir09mn	numeric
ir10mn	numeric
ir11mn	numeric
ir12mn	numeric
ir_year	numeric(10,0)
height	double precision
height_rel	double precision
build_en	character varying(100)
objectid	numeric(10,0)
geom	geometry(MULTIPOLYGONZM, 32632)
irradiance_geom_gist index	
pv_monuments_pilot	
gid	integer « pk nn »
TIPOP	character varying
NUM	character varying(11)
KGEM	integer
NR_KULTIS	integer
KODEX_UNTE	character varying(15)
BESCHR_KA6	character varying(254)
BESCHR_KA7	character varying(254)
BESCHR_UN8	character varying(254)
BESCHR_UN9	character varying(254)
UNTERSCH10	character varying(254)
UNTERSCH11	character varying(254)
OBJEKTBE12	character varying(254)
OBJEKTBE13	character varying(254)
KODEX_KATE	character varying(9)
VERWALTU15	character varying(180)
VERWALTU16	character varying(180)
KATASTRA17	character varying(180)
KATASTRA18	character varying(180)
TYPE	character varying(22)
the_geom	geometry(POLYGON, 32632)
public.v0_temp_average_year	
rid	integer « pk nn »
rast	raster
filename	text
v0_temp_average_year_rast_gist index	
public.buildingcode	
featurebuild_id	integer « pk nn »
objectit	character varying(60)
objectde	character varying(60)
objecten	character varying(60)

Figure 4.6: Database design.

sion below. The question marks represent the coordinates and SRID code of the requested point.

```
"SELECT _ST_Value(rast, _ST_Transform
(ST_SetSRID(ST_MakePoint(?, ?), ?),
_st_srid(rast)), _true) _temperature
FROM_" + db.temperature_table
```

GeoServer is an open source software server written in Java that allows users to share and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards (User Manual GeoServer 2.5.x (2014)). Besides the GeoWebCache is integrated with the GeoServer WMS that lets cache and retrieve tiles of the data. GeoWebCache is a Java Web application used to cache map tiles coming from a variety of sources such as OGC WMS. Moreover, implements various service interfaces (such as WMS-C, WMTS, TMS, Google Maps KML, Virtual Earth) in order to accelerate and optimize map image delivery (GeoWebCache 1.6.0 Home (2014)). The caching could be specified directly in Geoserver as well as during the export of raster data into PostgreSQL.

As it was underlined by Giuliani et al. (2011), discovering and evaluating data through their metadata is the first functionality that users can expect from an SDI. If the users know the existence of a specific data set, they could have the possibility to access it either by direct download or through Web services. Based on it, as a part of the development the connection to the spatial catalog Geonetwork should be performed. Within the Spatial catalog the metadata for the used data should be included, therefore the users can retrieve all the necessary details in the INSPIRE format within the Geonetwork interface, that is widely accepted among scientific collaborators in Europe.

Chapter 5

WebGIS Implementation

5.1 Setup System Requirements

In order to start with WebGIS development it is important to analyse the requirements to the assignment, software and final results.

Technical Requirements

The implementation of WebGIS application should be done in the framework of the standards that have been established for data storage and data visualization within the Institute for Applied Remote Sensing, EURAC. The work should fulfill the following requirements:

- Philosophy of Open Source software;
- OGC Implementation Standards;
- Resolution over urban area should be higher than 5 meters and 25 meters over rural areas;
- Should be applicable at any area of interest;
- The method should be applied independently on single steps.

User Requirements for WebGIS application

To understand the user demands the Institute for Applied Remote Sensing, EURAC had organized a workshop where experts involved in the organization, distribution, finance, installation and maintenance of PV-systems answered the questions and expressed their own requirements according to their experience. It is important to know the expert requirements, due to the fact that casual users have only little knowledge about the characteristics of the solar systems. The questionnaire that was developed within the following research can be

found at Appendix A. Therefore, the survey embraces the key issues about the data processing and data representation.

Afterwards, under the analysis of the workshop results, the user requirements were presented by means of infographic. The infographic is available in Appendix B. The results can be interpreted controversially, because along with the common parameters the experts require some technical information. They are interested in the data that could give them additional information for the further work, for example the cloud correction information, which is most probably has no meaning for a common user. Furthermore, all the experts came to the conclusion that the sums of the data should be produced on monthly and yearly basis. What's more, the wide interest in the data download, in particular in the solar radiation and horizon data, was expressed. When it come to the future development, most of the experts would like to see the information about the installed systems, solar potential on building facades and printed report.

Besides, there are some requirements that were addressed by the Province of Bolzano and partners of the project "Solar Tirol". First of all, the information should be given for sub-surfaces of the roofs to supply with high level of details. The PV efficiency and PV production should be calculated according to the latest approaches with cloud correction and Linke turbidity for 10 years of observation.

As a result of the workshop some specific user requirements were addressed. However, there are some constraints towards presenting all the requested parameters. The most significant limitation is applied for the data storage. Besides, according to the requirements of the scientific collaborates, the photovoltaic parameters should be calculated every 15 minute interval and the sum should be computed out of these values. However, the computational effort would be too high. Therefore the calculations of solar potential parameters are done using the monthly sums for irradiance and ambient temperature. As the result the performance of the WebGIS application is enhanced. Furthermore, the cloud correction is not applied, that can lead to results higher than expected. What's more, since the following work is concentrated on two pilot sites, the area of interest is limited.

To sum up, according to the requirements, some of them are feasible to fulfill in the following research, whereas for some, further data processing and application improvements should be done. Therefore, in order to balance the requirements, constraints and actual resources, the conceptual and logical data models are developed. Consequently, it would be possible to evaluate the feasible scope of work and to plan the activities for the future development.

5.2 Architecture of Solar Tirol WebGIS

The WebGIS application has a three-tier architecture. The front-end (presentation layer) is incorporated in a Web Browser and the implementation of the layout and interaction is done in JavaScript, JSP and CSS. The middleware (application layer) component uses Apache as Web Server and Apache Tomcat as Servlet Engine. On the Servlet Engine there are running two servlet containers: on one container there is running the rendering engine (Geoserver) and the other container is responsible for the configurations of the WebGIS. The configurations are stored in an XML configuration file and include client and server side settings. The back-end (data layer) comprises the access to file data sets (raster or vector) and to a DBMS. The entire WebGIS architecture is completely based on Open Source Software without any license restriction.

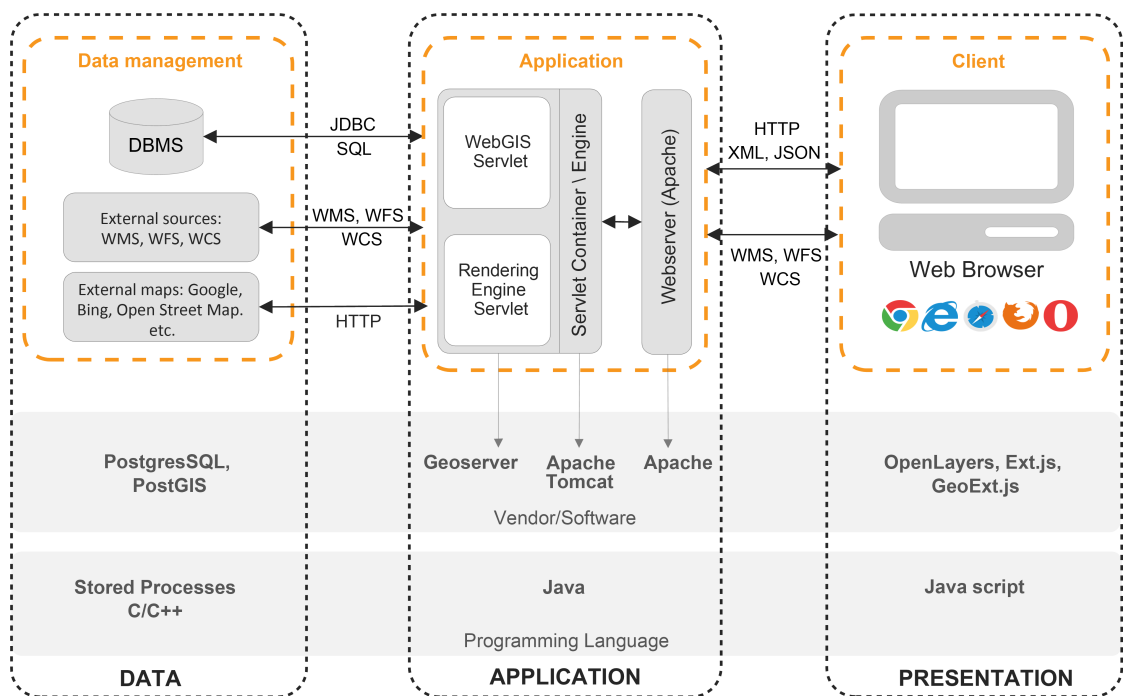


Figure 5.1: Three-tier WebGIS Client-Server Architecture. The architecture is specifically designed for a WebGIS application. It consists of the presentation layer, application layer (middleware) and data layer (persistence).

The figure 5.1 shows the three-tier architecture specifically designed for a WebGIS application. The presentation layer represents the access point to the user, which via a Browser (Chrome, Iexplorer, Safari, Mozilla, Opera, etc.) can interact with the system. The software components used on the client are the JavaScript Web Mapping framework Openlayers and the GUI framework Ext.js with its extension GeoExt.js. OpenLayers is a generic mapping

component, designed to consume spatial data and maps from numerous sources and display that data in a Web browser. It can display maps from Google, Bing or Open Street Map, and also display custom maps generated by rendering engines like GeoServer. In addition to map display, Openlayers provides tools for data editing and capturing (digitizing, altering, and moving features). Openlayers also provides a lightweight version for mobile devices (smartphones). The GeoExt/ExtJS framework comprises standard GUI components, including pre-built components for lists, panels, tables, dialogues and so. Further GeoExt adds some functionality to bind basic ExtJS GUI components to the spatial features of OpenLayers. For example, a GeoExt “selection manager” which looks like a table in the user interface is bound to the set of selected features in OpenLayers. The client communicates with the Web Server via the Internet Hypertext Transfer Protocol (HTTP) protocol. The content is exchanged using standardized OGC service (WMS, WMTS, WFS, Web Map Context (WMC)). The exchange format is XML and JSON for textual content and SVG, PNG or JPG for binary content (images).

In front of the application layer (middleware) a WebServer accepts requests, delegates them to the Servlet Engine and depending on the type of request the corresponding servlet is invoked. The WebGIS Servlet cares about requests specifically for that WebGIS application (configurations, etc.), the Rendering Engine Servlet (Geoserver) is responsible for the creation of images (WMS) and the query on spatial data. Geoserver (<http://geoserver.org>), an open source rendering server written in Java. GeoServer implements most of the OGC standards and can read from multiple data sources: tables in a database (PostGIS) or just spatial files on a hard drive, (e.g. ESRI Shapefiles or GeoTIFF images). The Geoserver map/feature server presents these spatial data as feature collections, and allows HTTP clients to perform operations on those collections to retrieve maps and information. Such as WMS for retrieving cartographic images or WFS for querying and retrieving vector feature collections. The GeoWebCache tile server sits between tiled mapping components (like OpenLayers) and rendering engine in GeoServer, and can intelligently store and serve map tiles. It caches the results for performance reasons. GeoWebCache receives tile requests, checks its internal cache to see if it already has a copy of the response, returns it if it does, or delegates to the rendering engine (GeoServer) if it does not. In the meantime is GeoWebCache has been incorporated into Geoserver as an internal module.

The data layer (persistence) contains the open source product PostGIS a spatial extension to the relational DBMS PostgreSQL, and inherits all the features of the underlying database. In addition, PostGIS adds types, functions and indexes to support the storage, management, and analysis of geospatial objects: points, linestrings, polygons, multipoints, multilinestrings, multipolygons and geometry collections. So the PostGIS database is able to answer spatial queries as well as standard attribute queries.

Table 5.1: Software components used in EURAC WebGIS products

Description	Version	Software	Layer
DBMS	9.1 (or newer)	Postgres	Data
Spatial Extension	2.0 (or newer)	PostGIS	
WebServer	2 (or newer)	Apache	Application (Server)
Servlet Engine/- Container	6.35 (or newer)	Tomcat	
Java Programming language	JDK 1.6 (or newer)	Java	
Rendering Engine	2.5 (or newer)	Geoserver	
Web UI Framework	3.4.1	ExtJS	Presentation (Client)
Web Mapping Framework	2.13.1	Openlayers	
Binding Framework (Geoext/Openlaers)	1.1	GeoExt	

The table 5.1 summarizes the software components with its versions used in the WebGIS products developed inside EURAC Research (<http://webgis.eurac.edu>)

Technical support: there are various companies providing a support for the used software components. The US Boundless (<http://boundlessgeo.com/>) provides a support for the products (PostGIS, Geoserver, GeoExt and Openlayers). The Italian company Geosolution (<http://www.geo-solutions.it/>) provides commercial support with strong competence in Geoserver.

5.3 Implementation

WebGIS Solar Cadastre offers the user different options through various features, as for example overlay with thematic layers, measuring tool, printing option, data download, identification tool and metadata overview.

The server and client architectures for Solar Cadastre are designed in a close connection. The server primarily retrieves information from the database by means of a query, produces estimations, generates response and sends it back to the client. In order to connect the client side with the server Asynchronous JavaScript and XML (AJAX) request is performed. Java Script executes an asynchronous HTTP request and provides updates with the response data. Moreover, a servlet is used to create dynamic content for a Web page. A servlet is a server extension provided by a Java class that can be loaded dynamically by the Web server (Barclay and Savage (2007)).

The current development stage can be summarized as follows:

- Geospatial data visualisation with Java Script, WFS and WMS;
- Interactions within the application (pan, zoom etc.) via OpenLayers library, GeoExt.js and Ext.js;
- Interactive map legend via Geoext.js component;
- Support of Geography Markup Language (GML) FeatureStyles provided by Geoserver;
- Metadata retrieval via the Spatial Catalog;
- Feedback form through the WebGIS environment;
- Geocoding.

The data is stored in the database, and the rendering is performed via Geoserver. The layers are organized according to workspace and stores that are connected to the PostGIS database. Each layer within Geoserver has some basic information as name, abstract, projection code, bounding boxes. Apart from it a set of keywords could be specified. These keywords let the application code to manage the layers according to particular purposes. Therefore, the following keywords are used within the application:

- “initial enabled” makes the layer visible by default,
- “metadata uuid=. . .” connects the layer to its metadata,
- “isBaseLayer” assigns the layer to overlays,
- “polygon”, “raster”, “point” and “line” define the layer type,
- “isOnTop” brings to foreground,
- “theme” assigns the layer to the topic group.

Among the offered functionality, some are predefined and provided by the OpenLayers library, as for instance: Overview Map, Pan, Zoom, Mouse Position, Navigation. Whereas, other functions required an additional effort to be implemented. For example, GetFeatureInfo is a functionality for requesting information about a selected feature. Let’s have a closer look on how it works.

The feature can be selected by clicking with the right mouse click on the interesting object. By selecting the feature is highlighted to be distinguishable from the other (see the figure 5.2).

```
.....
var wmsInfo = new OpenLayers.Control.WMSGetFeatureInfo({
    url : config.geoserverURL + "/wms", infoFormat : 'application/vnd
        .ogc.gml',
    maxFeatures: 3, queryVisible : true, eventListeners: {
        "beforegetfeatureinfo": function(event)
```



```

{if
  (window.popup != null && window.popup != undefined)
  {window.popup.destroy(); window.popup=null; }
  if
    (highlightedLayer.features[0]!==undefined)
    highlightedLayer.destroyFeatures(); },
  "getfeatureinfo": function(event) {
    ....
    var selectPoint = olMap.getLonLatFromPixel(event.xy);

```

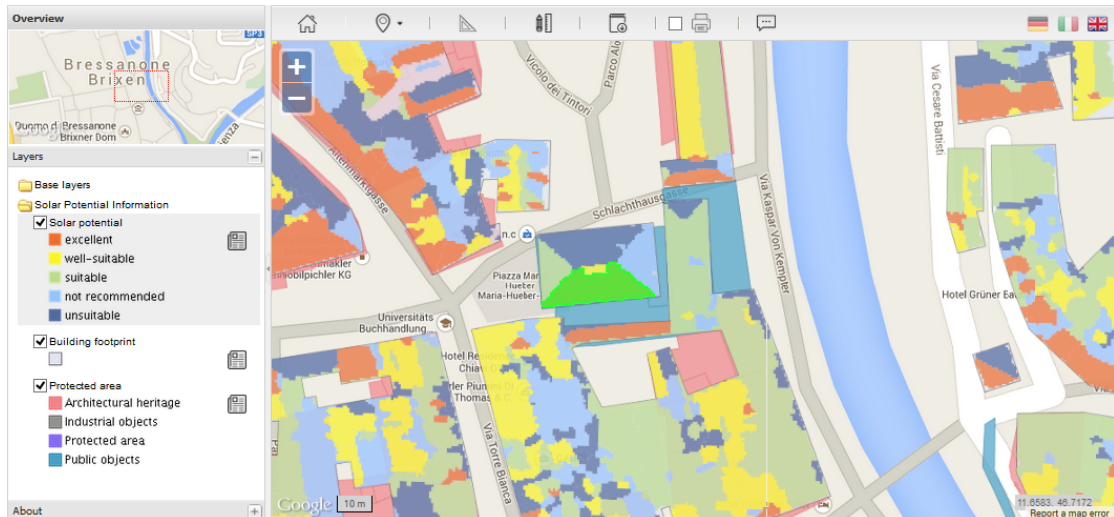


Figure 5.2: Select and highlight the object with right mouse click.

The control *WMSGetFeatureInfo* makes a WMS query to obtain the details about a point on the map. The information is acquired as GML format, that allows to read attributes from the response in order to compose our own output. Before the request is sent, the previous “GetFeatures” should be canceled out.

When response is received, the array of the objects is parsed over the position of the mouse click.

```
Ext.each(event.features, function(feature) {
```

The query is done for each feature with the relevant attribute. In our case it is information about irradiance. Therefore, the call to Java Servlet is performing by AJAX. By means of AJAX request the application can access the data from the server and parse it to the client. The request is done for the each selected feature. The queried features will be encoded from an array to the JSON string. The client sends to the server:

- Coordinates (x, y),

- Irradiance as JSON string
- Projection code.

```

.....
var myfeaturesJSON = Ext.encode(featuresToQuery);
Ext.Ajax.request({
method : 'GET', url : config.configURL,
params : {
    x : selectPoint.lat,
    y : selectPoint.lon,
    srid : mapPanel.map.projection.projCode,
    features : myfeaturesJSON,
    type : 'data'
},
success : function(response, request) {
.....

```

Therefore, the parameters are passed to the Servlet for the further processing.

```

.....
String paramX = request.getParameter("x"); String paramY =
request.getParameter("y"); String paramSrid = request.getParameter
("srid");
.....

```

To produce the estimation of the solar potential characteristics the value of the irradiance is not enough. Therefore, PostGIS query is executing the request to the database according to the sent parameters, namely coordinates and Spatial Reference System Identifier (SRID) to extract the temperature. However, the temperature data has different projection as the irradiance. Therefore, to obtain the temperature raster value, the projection transformation of the point should be done. For this reason the SQL request consists also “ST Transform” geometry editor, which returns the geometry in the same spatial reference system as the parsed SRID parameter.

```

.....
public final List<Double> getTemperature(double x, double y, int
srid) {
.....
List<Double> recordIds = new ArrayList<Double>(); String point = "
POINT(" + x +
"_" + y + ")"; try { connection = datasource.getConnection();
pStmt =
connection.prepareStatement
("SELECT_ST_Value

```

```
(rast, ST_Transform(ST_PointFromText(?, ?),
st_srid(rast)), true) temperature FROM "
+ Config.getInstance()
.getProperty("db.v0_temp_average_year_table"));

.....
recordIds.add(rset.getDouble("temperature"));
.....
```

Furthermore, the object node is created:

```
.....
ObjectMapper objectMapper = new ObjectMapper();
ObjectNode result = objectMapper.createObjectNode();
.....
```

Afterwards, the JSON object with features is parsed as a string object, from which the insolation value can be obtained. Therefore, the irradiance is estimated considering number of days and average number of solar hours during the month.

```
.....
JsonParser myfeaturesJSON
=objectMapper.getJsonFactory()
.createJsonParser(request.getParameter("features"));
ArrayNode myfeatures = (ArrayNode)
objectMapper.readTree(myfeaturesJSON);

for (JsonNode myFeatureNode : myfeatures ) {
    String fID = myFeatureNode.get("fid").getTextValue();
    Double irradiance =
    (myFeatureNode.get("irradiance")
    .asInt()) / DYS / HYR;
    .....
}
```

Eventually, the calculation of the module temperature, efficiency, electrical power, electrical energy, output power of photovoltaic system and emission savings for both technologies, CdTe and pcSi, and for different ventilation systems could be estimated according to the established methodology described in the chapter 3.2. Finally, the object's outputs will be written to JSON object. Content type application/json specifies the return format.

```
.....
ObjectNode featureNode = mapper.createObjectNode();
featureNode.put("....", ....);
.....
result.put(fID, featureNode);
.....
```

```

response.setContentType("application/json");
PrintWriter out = response.getWriter();
out.print(result);
out.flush();
.....

```

On the client side the success callback function returns the JSON object with the estimated data.

```

.....
success : function(response, request) {
    if (response.responseText != "") {
        var featuresWithTemperatures =
            JSON.parse(response.responseText);
    }
    .....

```

Therefore we obtain the response from the server with JSON object, that contains all the calculated information for each feature. The bar chart for irradiance information is obtain as JsonStore.

```

.....
var store = new Ext.data.JsonStore(
{ fields:['month', 'columnName','columnValue'],
  data: radData
});

```

Moreover, this information should be pushed to a panel, that will be visually available to the user. To do so some panels are created: property grid with “Averaged values during the year”, panel for “Annual insolation distribution, W/m²” with the bar chart, panel with “Performance Assessment depending on the ventilation” and eventually another property grid for additional information about buildings and monuments. The data have some attributes that should be hidden from the user, since some of them are used for the calculations with no need in their visualization or they are stored for the future development. Therefore we exclude them from the visualisation by means of searching the attribute key in the item and deleting it from the visualization, but not from the database.

Apparently, the Popup window should be introduced. Due to the fact that we have two kinds of features, those that contain information about irradiance and those that does not, we need to create two Popup windows.

```

window.popup = new GeoExt.Popup({
    title: "Solar_Potential_Characteristics",
    width: 500,
    height: 400,
    layout: "accordion",

```

```

        autoScroll: true,
        unpinable: false,
        map: mapPanel,
        autoDestroy: true,
        draggable: true,
        collapsable : true,
        location: event.xy,
        anchored: false,
        closeAction:"destroy",
        multi: false,
        items: items,
    } );
window.popup.show();
.....
    } else {
.....
window.popup = new GeoExt.Popup({
    title: "Feature_Info",
    width: 500,
    height: 400,
    layout: "accordion",
    autoScroll: true,
    unpinable: false,
    map: mapPanel,
    autoDestroy: true,
    draggable: true,
    collapsable : true,
    location: event.xy,
    anchored: false,
    closeAction:"destroy",
    multi: false,
    items: items,
    } );
window.popup.show();
.....

```

Besides, the connection of the layers to their entries in the spatial catalog is provided as it is illustrated in the figure 5.3. GeoNetwork provides the so-called Universally Unique Identifiers (UUID), that complies with the INSPIRE metadata implementing rules (Shvaiko et al. (2010)). The Identifier UUID of the metadata was used to connect the Data with their entities in the Catalog. Therefore, to connect the metadata from the catalog to WebGIS application the XML constructor was introduced.

```

OpenLayers.Format.XMLParser = OpenLayers.Class(OpenLayers.Format.
XML, {

```

```

initialize : function(options, uuid, catalogUrl) {
    OpenLayers.Format.XML.prototype.initialize.apply(this, [ options
    ]);
    this.options = options;
    this.uuid = uuid; this.catalogUrl = catalogUrl;
},

```

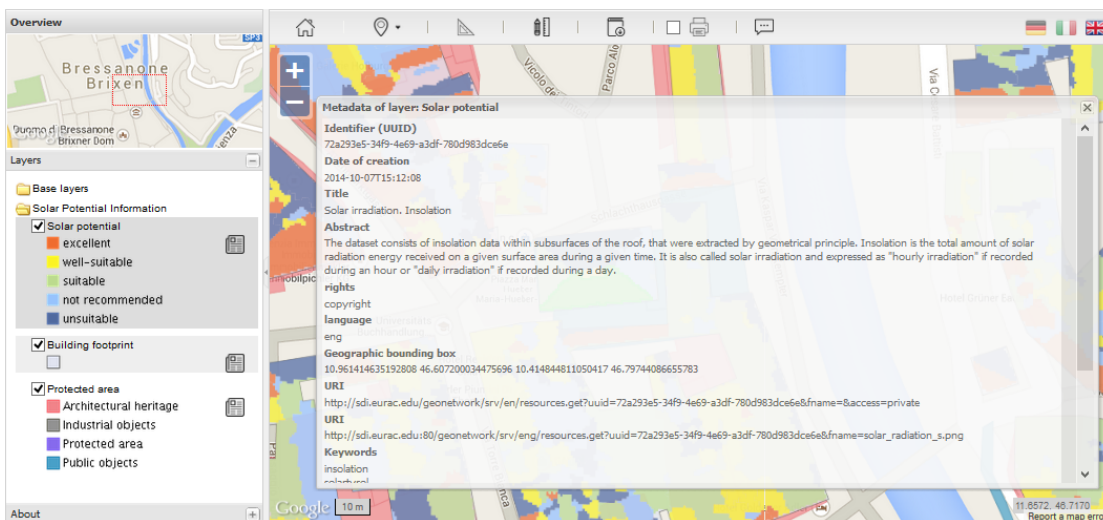


Figure 5.3: [Metadata connector. The connection of the layers to their entries in the spatial catalog is performed by means of XML constructor.

The OpenLayers.Format.XML constructor could read and write XML. Therefore it is used for cross-browser XML generation based on the methods of the XML format class. For the each specified entry in the metadata XML the string in the HTML form is created. Among the elements that are read from the XML metadata are Identifier (UUID), Title, Date of creation, Date of revision, Geographic bounding box, Abstract, Source and Description.

```

case "identifier":
    content += "<tr><td_width='10%'><b>Identifier_(UUID)</b></td></tr><tr><td>"
    + childNode.children[j].firstChild.data + "</td></tr>";
break;

```

Moreover, a user could leave a feedback by using the "Contact us" form as it is shown in the figure 5.4. To implement this option, the connector for the email address should be introduced. Firstly, the graphic interface was created that includes a button on the tools bar, window for a panel and the panel form which should be filled out. The panel consists of

the items as name, email, title and comment. The button Submit triggers the request to the Servlet, where the letter to the administrator is generated.

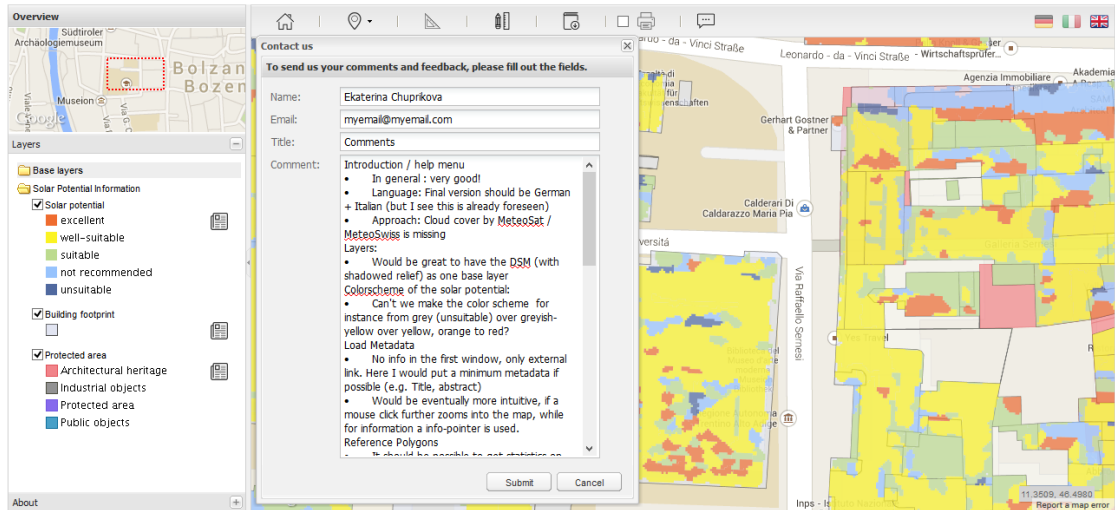


Figure 5.4: The Feedback form is provided to offer the possibility for communication between a user and a developer which can bring forward new improvements and fix the problems that users might face. The form supplies with the tool to report or leave a comment about the application. There are some fields that should be filled in, among them are name, email, title and the comment.

```
function createDownloadFormPanel () {
    return new Ext.FormPanel({
        labelWidth : 75, // label settings here cascade unless
                        overridden
        standardSubmit : true,
        frame : true,
        title : 'To_send_us_your_comments_and_feedback,_please_fill_out_
                the_fields.',
        bodyStyle : 'padding:5px_5px_0',
        width : 320,
        defaults : {
            width : 300
        },
        defaultType : 'textfield',

        items : [ {
            fieldLabel : 'Name',
            name : 'name',
            allowBlank : false,
            minLength : 1
        }, {
            fieldLabel : 'Email',
```

```

        name : 'email',
        vtype : 'email'
    }, {
        fieldLabel : 'Title',
        name : 'title',
        allowBlank : false,
        minLength : 1
    }, {
        fieldLabel : 'Comment',
        name : 'comment',
        allowBlank : false,
        xtype : 'textarea',
        height : 100,
        minLength : 1
    }
],
buttons : [ {
    text : 'Submit',
    handler : function() {
        var fp = this.ownerCt.ownerCt, form = fp.getForm()
        ;
        if (form.isValid()) {
            if (fp.baseParams && !fp.paramsAdded) {
                // add hidden items for all baseParams
                for (i in fp.baseParams) {
                    fp.add({
                        xtype : 'hidden',
                        name : i,
                        value : fp.baseParams[i]
                    });
                }
                fp.doLayout();
                // set a custom flag to prevent re-adding
                // fp.paramsAdded = true;
            }

            var formParams = fp.getForm().getFieldValues();
            formParams['type'] = 'email';

            Ext.Ajax.request({
                method : 'GET',
                url : config.configURL,
                params : formParams,
                success : function(response) {
                    if (response.responseText != "") {

```



```

        Ext.getCmp('downloadInfo').update("<h1>Your_request_was_
        forwarded_to_the_responsible_person._Thank_you_for_
        valuable_feedback._</h1>");
    }
}
});
}
}, {
    text : 'Cancel',
    handler : function () {
        Ext.getCmp('downloadInfo').hide(this);
    }
} ]
})
}

```

Therefore, the Servlet generates the letter and sends it to the administrator according to the defined email and password.

```

// Create a default MimeMessage object.
MimeMessage message = new MimeMessage(mailSession);
// Set From: header field of the header.
message.setFrom(new InternetAddress(config
    .getProperty("_email.sender")));
// Set To: header field of the header.
message.addRecipient(Message.RecipientType.TO, new InternetAddress
    (
        recipient));
message.setReplyTo(new Address[] { new InternetAddress(sender) });
// Set Subject: header field
message.setSubject("Comment_or_feedback_from_" + name);
String emailBody = "<h1>Name:_ " + name + "</h1>";
emailBody += "<h1>Title:_ " + title + "</h1>";
emailBody += "<h1>Comment:_ " + comment + "</h1>";
// Send the actual HTML message, as big as you like
message.setContent(emailBody, "text/html");
message.saveChanges();
// Send message
Transport.send(message);
rootNode.put("message", "Message_sent_successfully_to_" +
    recipient);
log.debug("Configuration_request:_ " + rootNode.asText());
response.setContentType("application/json");
PrintWriter out = response.getWriter();
out.print(rootNode);

```

```
out.flush();
```

Moreover, the password is available in the encrypted form that only authorized parties can read it. This helps to protect the private data from being revealed.

To sum up, the client requests service from a server by sending it a request. A Web browser represents the client GUI of the application or displays a particular response from the server. The server-side could play a significant role when it comes to the question of decreasing the data storage. Therefore, the client contains code of HTML and JavaScript, whereas the server can manipulate with the data and send the results to the browser.

5.4 Summary

The WebGIS Solar Cadastre allows access to the geospatial information in the Web environment using open-source. The architecture of the WebGIS provides the most dynamic interaction and high level of functionality with the data due to its possibility to connect the Web browser, Web server and spatial database. Moreover, it offers a simple user interface which works with the WMS and WFS services. The WebGIS is built with Javascript interface using OpenLayers, GeoExt.js and Ext.js in dependence with Geoserver and PostgreSQL. The methodology was implemented in a way that a user could estimate the characteristics on-the-fly by identifying a feature from the digital map. The Servlet produces the estimations and send the results to the client. The estimations are presented via pop-up window with the corresponding information about irradiance distribution, electrical power, electrical energy, emission savings and photovoltaic output. Moreover, the Web GIS Solar Tirol is developed within SDI EURAC that provides an easy access for collaboration and distribution of solar potential data.

Chapter 6

Results and Analysis

6.1 Study Area and Audience

The research is applied on the study area in the Autonomous Province of Bolzano (Alto Adige / Südtirol), Northern Italy. South Tyrol is a mountain region with the total surface area 7400.43 km² (South Tyrol in figures (2013)), 504.643 habitants (2011) and various climate zones. Initially, the research should have been carried out for the whole South Tyrol, however it was decided to scaled down the area to the cities of Bozen / Bolzano and Brixen / Bressanone, due to high computation effort needed for processing the original data, which was produced for the main valleys in South Tyrol.

Bolzano lies in the heart of Dolomites in northeastern Italy on the height above sea level of 254 m. Based on the statistics South Tyrol in figures (2013), the mean air temperature is 12.3 °C and average rainfall is 710.2 mm. As regards Bressanone, the city is located on 560 m above see level and it has mean average temperature 10.0 °C and the rainfall about 661.7 mm. According to the data from 2011 South Tyrol in figures (2013), the population of Bozen and Brixen reaches 102,575 and 20,677 people respectively. The extent of the LIDAR flight campaign and pilot areas in respect to the Province of Bolzano could be seen in the figure 6.1.

The pilot sites have 16 km² each and cover urban areas. All together it contains approximately 37305 residential, industrial and commercial buildings. The geometry of the buildings was provided by the Autonomous Province of Bolzano and it is dated up to 2006 year. The following work is aimed for the residents, industries, public authorities and decision makers in order to provide them with the information that can help to take a first step in analyzing the potential for solar PV at a particular location. The tool should be available on-line with free access to all interested parties.

A WebGIS application is a communication tool with geographical content, that provides

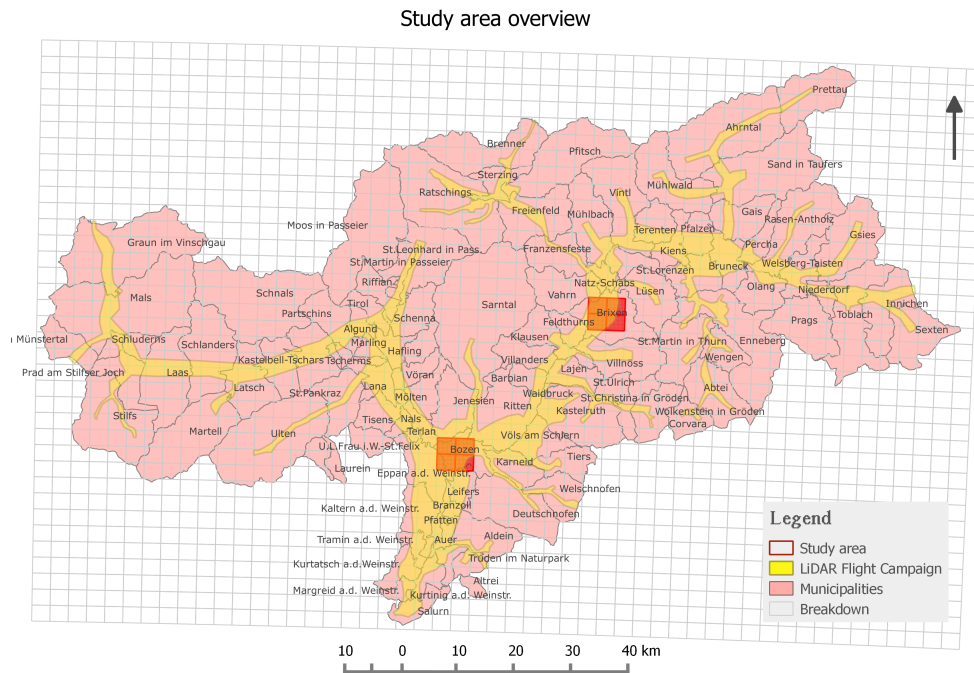


Figure 6.1: Extent of the study area. The research is applied on the study area in the Autonomous Province of Bolzano (Alto Adige/Südtirol), Northern Italy. South Tyrol is a mountain region with the total surface area 7400.43 km² (South Tyrol in figures (2013)), 504.643 habitants (2011) and various climate zones. The pilot sites have 16 km² each and cover urban areas. All together it contains approximately 37305 residential, industrial and commercial buildings

a user with a digital map that can serve to request information. The tool is working in two directions. Firstly, it shows the information visually, therefore a user can identify an interested feature. And secondly, a user can retrieve the detailed information by selection a feature from the map. Apparently, the WebGIS applications have a particular place in the data visualization, therefore this tool can serve as a user-friendly environment to transfer the knowledge to the wide public. Consequently, depending on the type of a user the tool can serve for the planning a solar system in a private or industrial building, urban planning, building renovations, promotion of renewable energy in the region and educational purposes.

6.2 Solar Tirol WebGIS

The created WebGIS is called “Solar Tirol”, available at [http://webgis.eurac.edu/solartirol/](http://webgis.eurac.edu/solartiro/), according to the name of the project organised by Land Tyrol, Austria and the Autonomous Province of Bolzano in collaboration with EURAC research. The application provides users with immediate access to the information about incoming solar

radiation on building roofs. In the main part of the application user can navigate the map and explore area of an interest. The front page of the application can be seen from the figure 6.2.

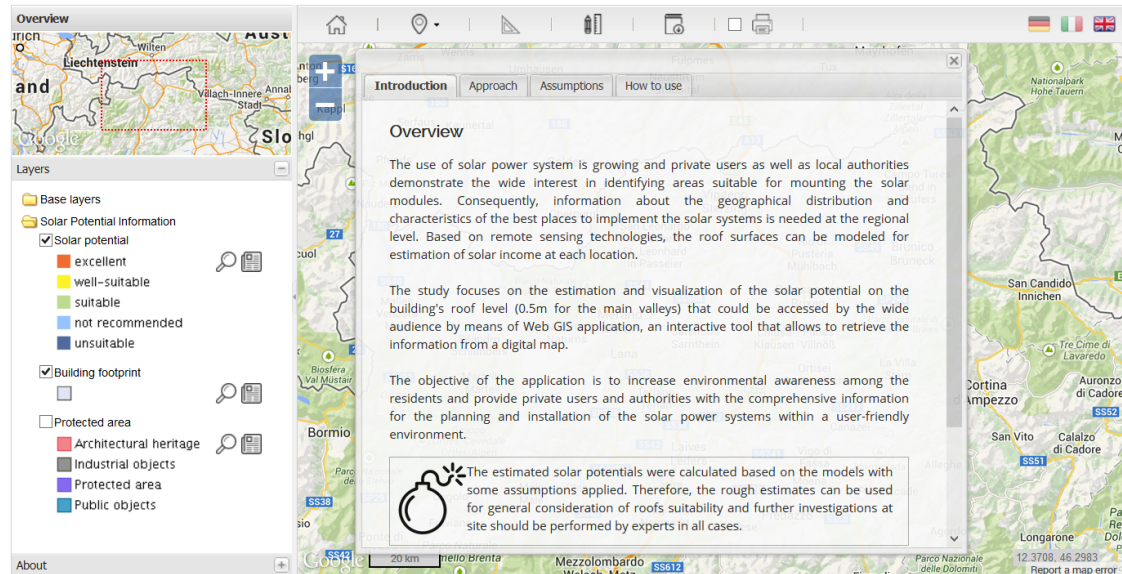


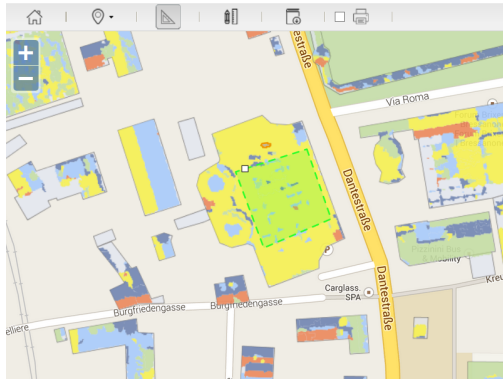
Figure 6.2: Solar Tirol WebGIS. A web-based-GIS interface has been set up to display the data to public and a spatial database has been developed to handle large amount of data. The WebGIS can provide communities with information that can drive sustainable practices, community awareness, energy efficiency, and smart development. The application is available at <http://webgis.eurac.edu/solartiro/>.

The layout of the application is organised using Ext.js and its extension GeoExt.js, pure JavaScript application frameworks for building interactive Web applications. The WebGIS has a set of GUI-based form controls. Therefore, the application includes map panel, overview map, legend panel and layer tree and imprint section.

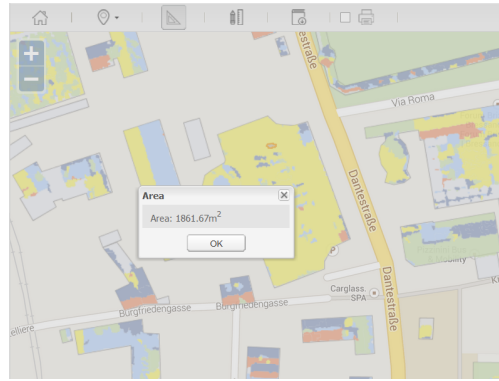
On the top left corner the Overview map gives the preview of an area of interest. The navigation functionality lets zoom in and out of the map, pan it, and change the map extent. Furthermore, on the left side panel the list of layers is presented, therefore only needed layers can be visualised. For each layer the respective legend is given which is active when only the layer is toggled. Hence, a user can visually identify the suitability of the roofs for solar panel installation. Moreover, there is a toolbar with buttons that perform operations for measurements, data download and print. Additionally, an information window provides with description of the application, approaches, assumptions and instructions of how to use.

The users can measure the area and length of a selected roof in projected plan that can assist in identification of area available for solar system.

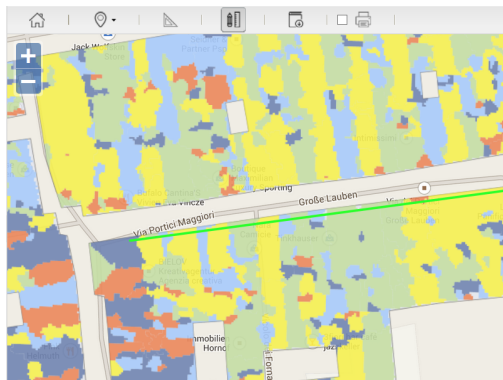
Besides, the data can be downloaded for visualization in Google Earth by saving it as



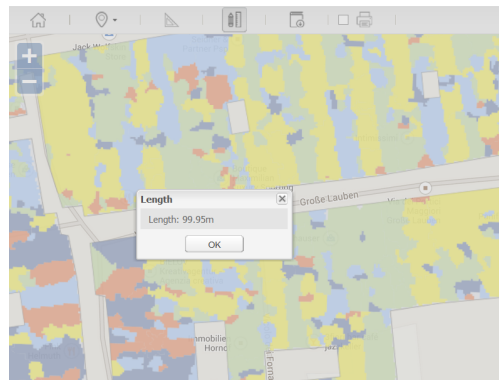
(a) Measure area



(b) Measure area



(c) Measure line



(d) Measure line

Figure 6.3: Measuring tool. The area and length of a selected roof can be measured in projected plan. This information can assist in identification of area available for solar system

Keyhole Markup Language (KML) file (see figure 6.4). KML allows to annotate and overlay visualizations on various two-dimensional, Web-based on-line maps or three-dimensional Earth browsers such as Google Earth as it is illustrated on the figure 6.5. Moreover, by using KML it is possible to mix and match the solar potential information with other sources as for example temperature, solar hours or aspect within Google Earth environment.

Furthermore, the functionality allows to retrieve the information about each particular feature by clicking on it. The pop-up window shows the details within an accordion layout sorted by the information type. As it can be seen in the figure 6.6, the user could obtain the information about amount of solar irradiance within selected feature and estimated parameters of solar potential characteristics. Besides, one gets the details about the building, where selected feature was taken from.

Moreover, the information about the data (metadata) could be directly accessed too. The metadata was created within GeoNetwork EURAC 6.7, a catalog application that lets

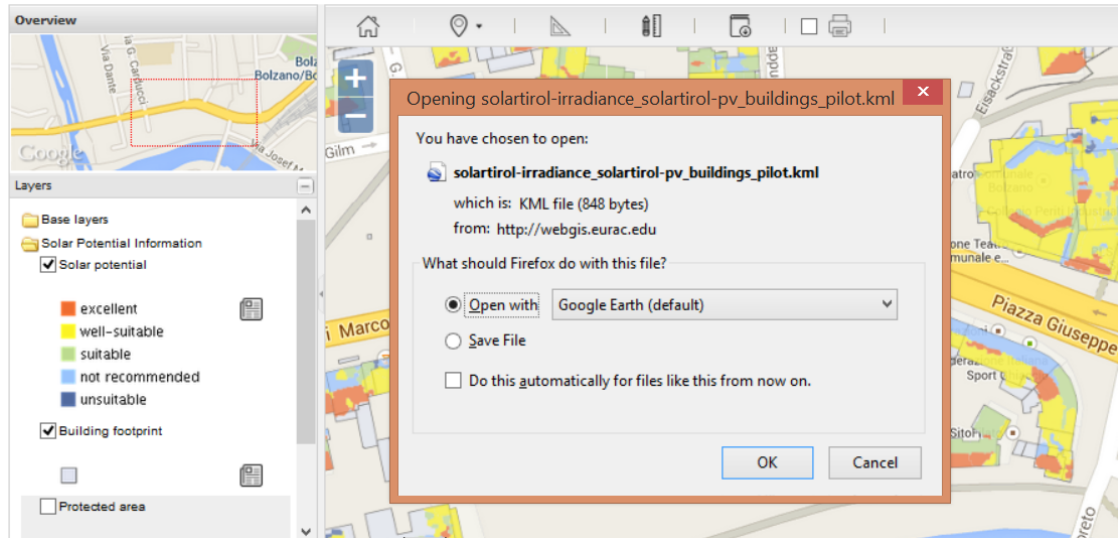
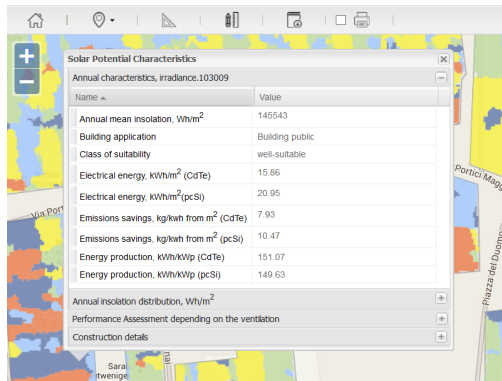


Figure 6.4: Download data as KML file. The layers could be downloaded as KML file, stored and visualised in three-dimensional Earth browsers such as Google Earth

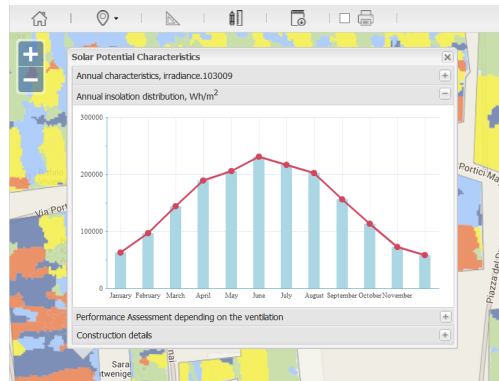


Figure 6.5: Solar Potential Data visualization in Google Earth. Using KML allows to annotate and overlay visualizations on various two-dimensional, Web-based online maps or three-dimensional Earth browsers such as Google Earth.

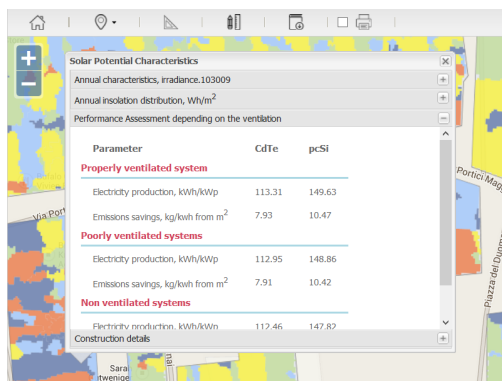
manage spatially referenced resources. It provides powerful metadata editing and search functionality as well as embedded interactive Web map viewer. The metadata was created following International and Open Standards that provide the format and content for properly describing the data. Due to the fact that the ISO 19115 “Geographic Information



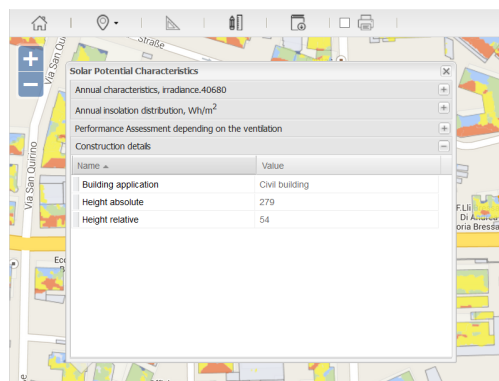
(a) Energy production and emission savings



(b) Monthly sums of irradiance, W/m^2



(c) Outcome with different ventilation condition



(d) Information about the building

Figure 6.6: Popup window with solar potential characteristics. The control *WMSGetFeatureInfo* makes a WMS query to obtain the details about a point on the map. The information about the feature is pushed to a panel, that is visually available to the user. To do so four panels are created: property grid with “Averaged values during the year”, panel for “Annual insolation distribution, W/m^2 ” with the bar chart, panel with “Performance Assessment depending on the ventilation” and eventually another property grid for additional information about buildings and monuments.

- Metadata from ISO/TC 211 is currently the main metadata format and it is supported by Geonetwork, it was used for creating the metadata.

As it is seen in the figure 6.8, the metadata window is requested from the interface by button and shows the main characteristics of the data. Among them are:

- Identifier (UUID) is an individual number of each metadata entry,
- Title of the Data,
- Date of creation,
- Date of revision,
- Geographic bounding box that shows the spatial extent of the data,

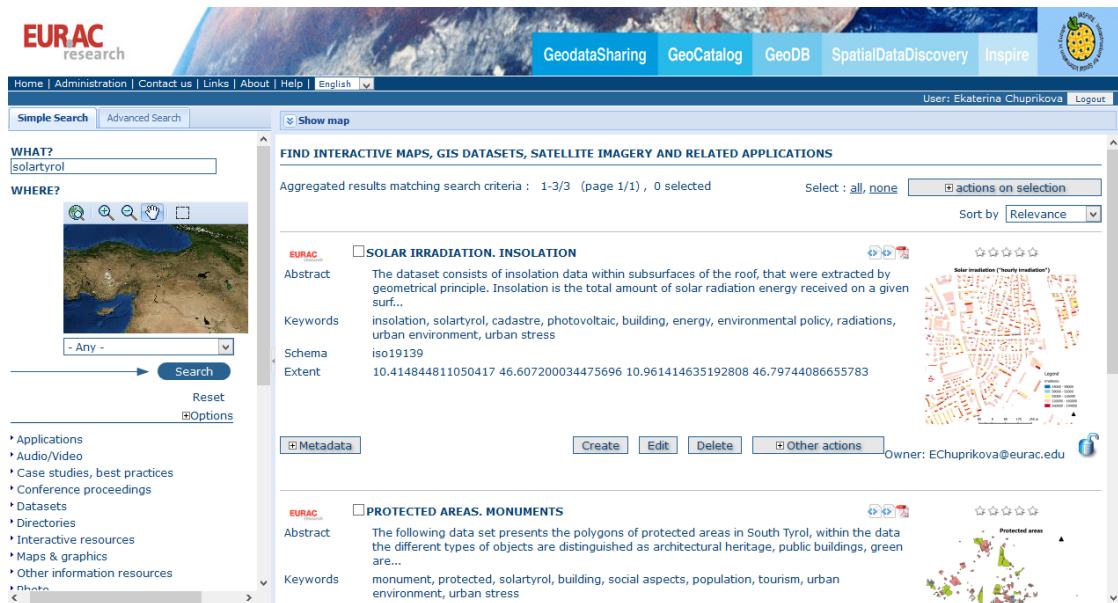


Figure 6.7: EURAC Spatial Catalog. Geonetwork is an open source that allows to share geographically referenced thematic information between different organizations. Moreover, it improves access to the spatial data, supports decision making, promotes multidisciplinary approaches and it enhances understanding of the benefits of geographic information.

- Abstract describes the information about the Data,
- Source of the Data,
- Owner of the Data,
- License.

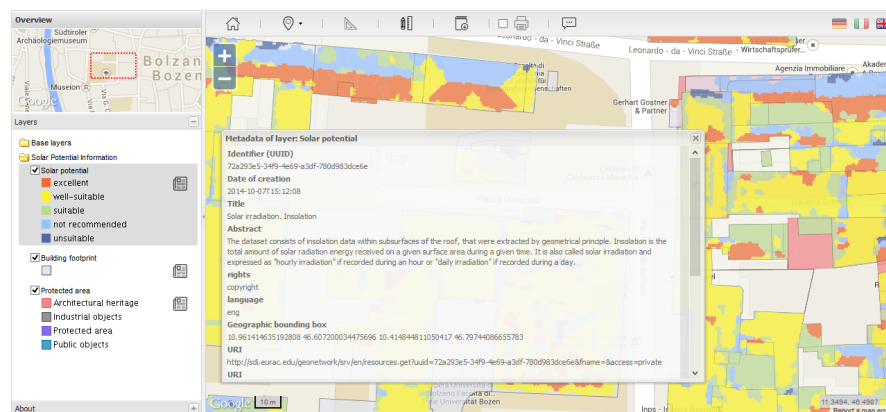


Figure 6.8: Metadata Information could be retrieved from the application using toolbar on the right side of the layer tree.

The window provided the metadata contains also a link to the Geonetwork EURAC, where the metadata can be viewed and downloaded (see the figure 6.9).

Figure 6.9: Metadata Information can be assessed via Geonetwork

Solar Tirol WebGIS application is going to become a part of EURAC SDI that supplies users with such additional benefits as:

- Straightforward access to the data,
- the data could be searched, discovered and shared,
- the data and metadata can be integrated into other systems via Web services,
- good coordination via Open Standards,
- cost effective technologies,
- flexible architecture.

Therefore, the solar potential data is accessible to wide audience via WebGIS and Spatial Catalog. Additionally, since the project was organized with support of Autonomous Province of Bolzano, the information can be shared via portal of the Province as well by means of Web services and metadata harvesting.

Moreover, the application provides users with the opportunity to leave a feedback. The special form was created to let users share their opinion about the application, ask questions, report about problems, leave a comment or suggestion. The created form (see the figure 6.10) gives the possibility to leave an email address for the further contact, therefore this form provides the way to contact with the end users and to improve the application according to their needs and suggestions.

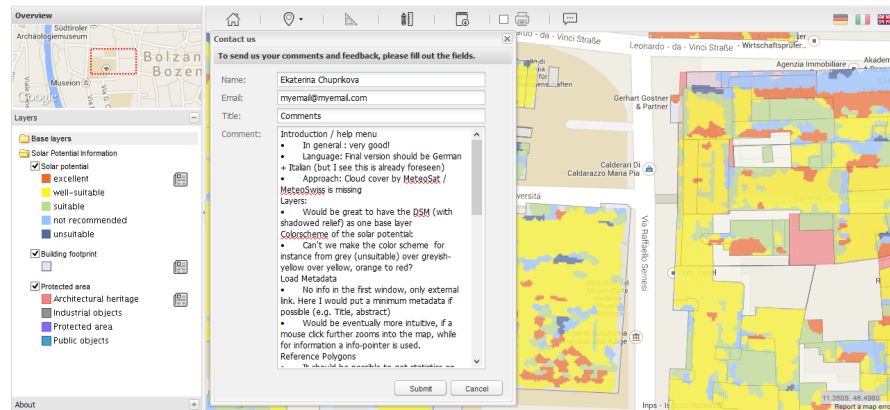


Figure 6.10: The feedback form is provided to offer the possibility for communication between a user and developer which can bring forward new improvements and fix the problems that users might face. The form supplies with the tool to report or leave a comment about the application. There are some fields that should be filled in, among them are name, email, title and the comment.

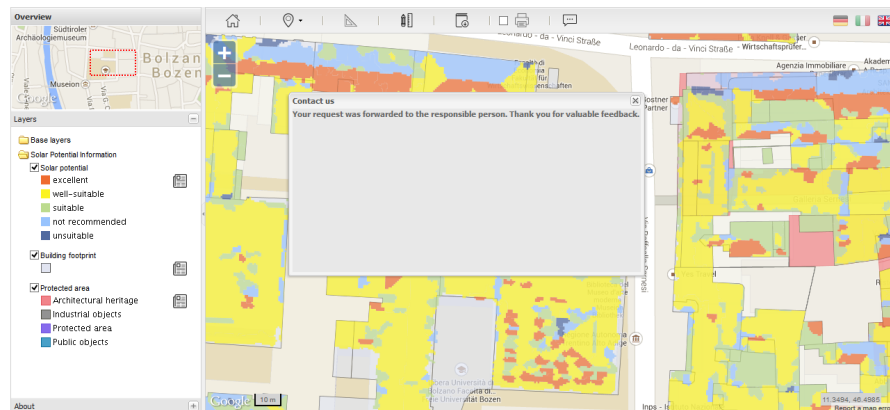


Figure 6.11: Once the comment is submitted, user can see a message about the successful operation.

6.3 Questionnaire Results

The first questionnaire was created for the workshop organized by Institute for Applied Remote Sensing, EURAC, where experts involved in the organization, distribution, finance, installation and maintenance of PV-systems answered the questions and expressed requirements according to their experience. Afterwards, under the analysis of the workshop results, the user requirements were presented in an illustrative way by means of an infographic. As it was defined by Smiciklas (2012) infographic is a visualization of data or ideas that tries to convey complex information to an audience in a manner that can be quickly consumed and easily understood. Therefore, the results of the workshop were interpreted in the graphical

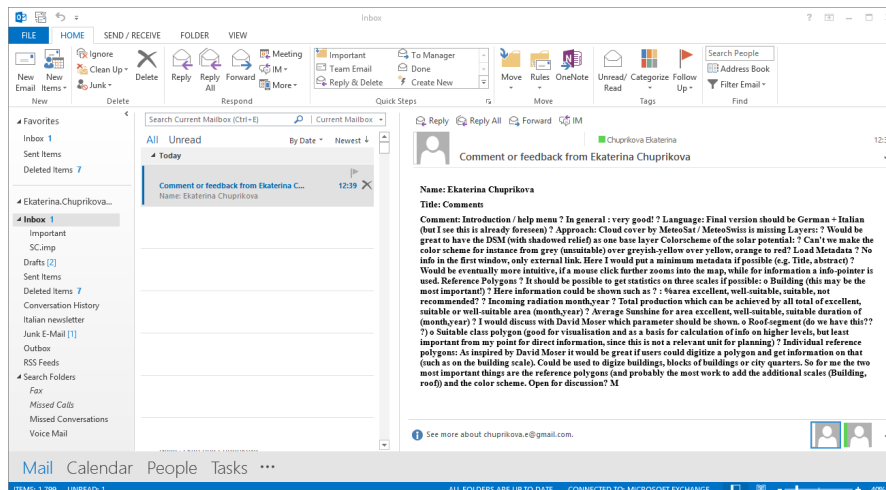


Figure 6.12: Contact developer via an email. Immediately, the administrator receives an email with the reported feedback.

way as it is illustrated on the figure 9.1. Besides the larger size infographic is also available in Appendix B. Among the requirements, there were some crucial for the data visualization as monthly and yearly parameters and data download. Therefore, according to the output of the questionnaire the further work could be planned including the expressed requirements. In spite of the fact that some of the parameters are not visualized, they should be included into the Spatial catalog as metadata entries.

In the final stage of the research, another questionnaire was developed to test the application on its usability in order to identify the drawbacks according to point of view of the experts. Therefore, the questionnaire defined in the chapter 3.5 was addressed. The full version of the results is available in the Appendix C. As the result of the survey, some reported problems were fixed straight away. Overall, most of the participants were satisfied with the work of the application, apart from those issues that were specified so far. The frequently mentioned mistakes are about PDF report and the metadata window were not relevant due to the fact that the application was run in the test regime.

Interface

Based on the questionnaire of usability the GUI was evaluated by the users according to some questions. The weighted average of the responses with the maximum value 5 can be seen in the figure 6.14.

However, there are some reported mistakes and recommendations concerning GUI that are gathered in a table 6.1.

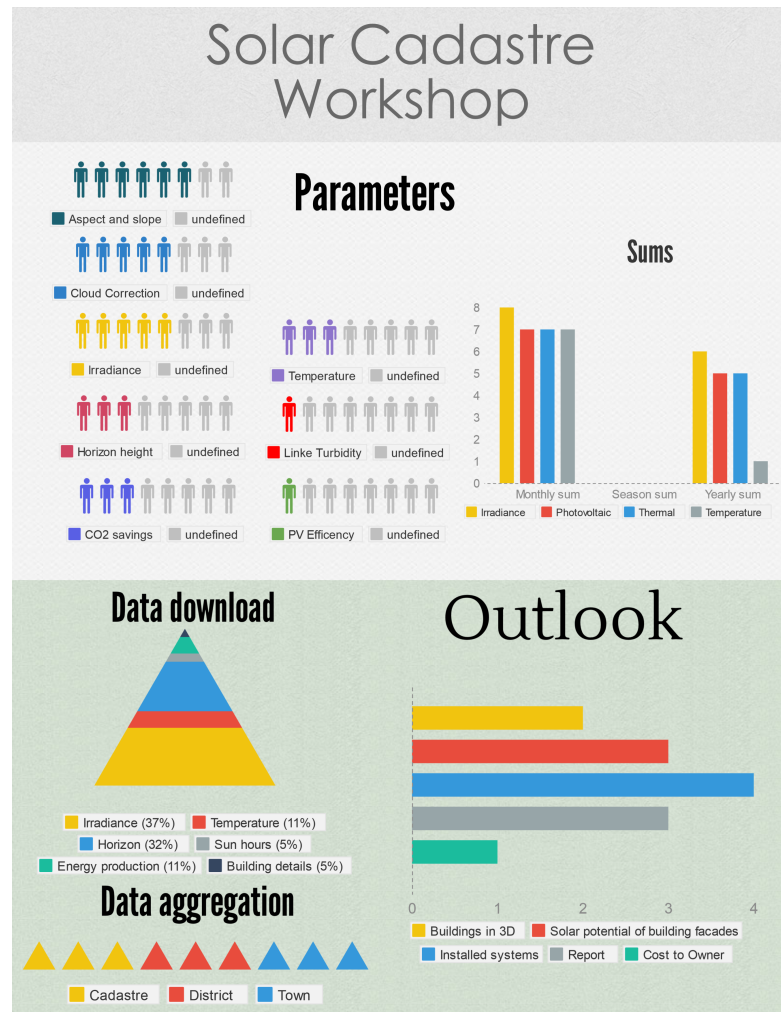


Figure 6.13: User Requirements Infographic. The larger version is available in Appendix B. Under the analysis of the workshop results, the user requirements were presented in an illustrative way by means of an infographic.

Content

Based on the results of the usability questionnaire, the content of the application could be evaluated as well. It is seen in the figure 6.15, in general, the users were satisfied. Results are presented as the weighted average of the responses with the maximum value 5.

However, there are some improvements that should be done towards enhancement of the solar potential parameters. The reported mistakes, recommendations and the statement of the improvement could be found in the table 6.2.

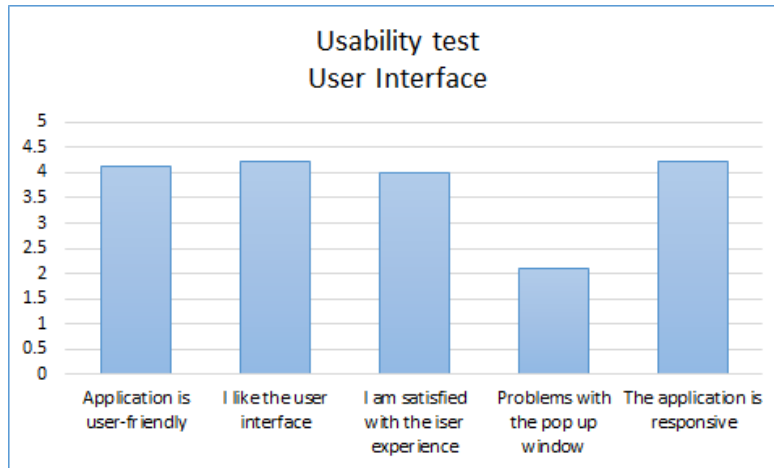


Figure 6.14: Evaluation of user interface. As it can be seen the weighted average with the maximum value of 5 represents the results of the evaluation of the user interface, therefore the most of the testers were satisfied with the user interface.

Table 6.1: Usability test. User interface

Problem	Current edition	Future development
Highlighted feature should appear in a different color	Done	
The pop-up window shouldn't cover the highlighted feature	Done	
Magnifying glass next to a layer node is confusion, because it changes the scale for a layer extend	It was decided to exclude this elements since with only two locations the layer extent is not needed	
The tool is not user-friendly enough for persons who are totally "ignorant" in the field	The more detailed description of the benefits should be done	The tool should provide with the step by step instruction
Information about base layers should be available in the welcome window	Done	

6.4 Summary

The use of interactive maps brings a lot of opportunities to visualize the solar potential information on a digital map, hence the Solar Tirol WebGIS is a tool that helps to provide municipalities, government agencies, utilities, engineering consultants, engineering contractors and private users with information about solar systems that is presented in convenient

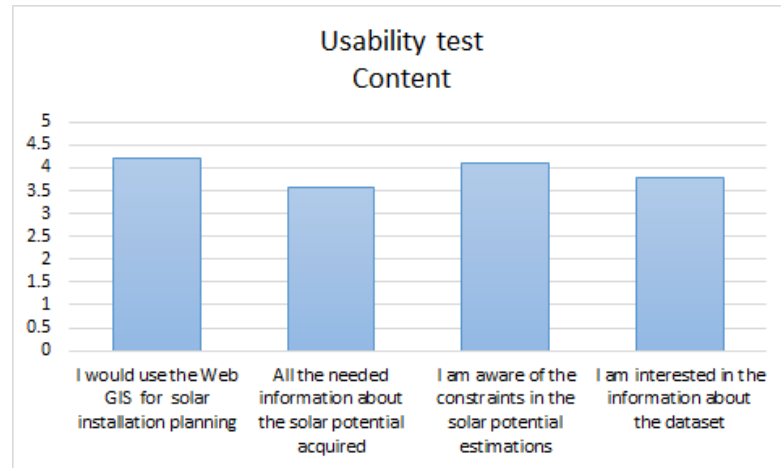


Figure 6.15: Evaluation of content of the application. Based on the the weighted average of the responses with the maximum value 5, it is seen that the users were agreed with the content, however there are some improvements that the experts would like to see in the future development.

Table 6.2: Usability test. Content

Problem	Current edition	Future development
Annual sums are preferable than average monthly sums	Done	
Calculation of areas and Energy yield/solar energy potential on tilted surfaces		Slope angle should be included into the data
The application should be available for a wider area		The future development is aimed to cover all the main valleys of South Tyrol

and interactive way. Therefore, the WebGIS serves as a tool to present the data, to educate users in a sphere of photovoltaic and to help in decision-making for solar installations.

The Solar Tirol WebGIS application includes digital basemaps, operational layers, tools and geodatabase. Furthermore, Google, Bing, Open Street Map APIs could be used as based layers, where users can find familiar interfaces of a street map, terrain or hybrid representation. The operational layers represent the information about insolation, cadastre data and protected areas. As regards the tools, they were defined according to user needs and include such basic tools as pan and zoom as well as more advanced as measuring tools.

Moreover, the WebGIS Solar Tirol was developed within SDI EURAC that provides easy access for collaboration and distribution of solar potential data. Therefore, the SDI technology can bring significant benefits for public organizations, local authorities and private

sector. Moreover, the SDI supplies with simple, interactive, and flexible access to geospatial data via Web services. Additionally, the SDI EURAC framework is based on industry standards, which include the OGC, INSPIRE, and the ISO.

What's more, the application is based on three-tier architecture that provides the following benefits:

- **Performance and Scalability.** An application server can be used to cache persistent data to increase performance and scalability. For example, Presentation tier could be harmoniously organised among three servers to satisfy more Web requests without adding servers to the Application and Data tiers. Besides, since the Presentation tier can cache requests, use of the network is minimized, and the load is reduced on the Application and Data tiers.
- **Availability.** The presentation layer supports caching which makes the process Web requests even if the application tier server is temporally down.
- **Security.** The middle-tier improves the security since it adds an extra level of indirection between the Web server and the database.
- **Reuse and maintenance.** The application layer can be shared by a number of clients, therefore reuse and maintenance is increased. Besides, the system can be reused by using the same structure, but applying another topic of interest by utilizing the components of the system.

In addition to that, the Solar Tirol WebGIS is future-oriented system that could be scalable on the different areas of the application. Besides, the database could be changed, but the working principle remains the same. Moreover, the system could be enhanced with new operational layers if it needed, that makes it flexible from the content point of view.

To sum up, the following work presents research and development of a prototype Web application for Solar Cadastre for South Tyrol using latest advancements in Web mapping, open source software and WebGIS.

The Web application is developed using several programming technologies (AJAX, JavaScript, Java servlet), Java script libraries (OpenLayers, Ext.js, Geoext.js) and open source software components (GeoServer, PostgreSQL, PostGIS). The presented Web application has several main benefits over classic thematic map or written guidance:

- Storing, retrieval and managing spatial data;
- Computational functionality, which allows to obtain the energy and power production for each particular feature;
- Support of spatial catalog, where the metadata is stored.

- Free access. The web-based application is available at anytime with Internet connection via Web services;
- Several users could work with the application;
- No need in installation of additional software;
- The implementation code is done according to well-defined structure and can be changed by any other expert;
- Flexible for additional features and solar potential parameters to add;
- Supports three-tier architecture that gives additional benefits as performance, scalability, availability, security, reuse and easy maintenance;
- The system is SDI enabled that brings significant benefits for data sharing, storing, maintenance and scientific exploration;
- The system is oriented towards open-source philosophy that includes using the industry standards OGC, INSPIRE, and the ISO;
- The approach could be used with another area of interest as well;
- The Presentation layer could be changed with the future development, whereas the Application layer can be still actual;
- The flexibility of the system lets change the estimations with advance parameters if it is needed.

However, the drawbacks should be mentioned as well:

- The application shows the approximate results and at-site investigations are needed in each case;
- The cadastre data should be updated and footprints from the LIDAR data should be considered too;
- Estimation of electrical power and energy is performed with the same temporal resolution as the insolation data. Therefore, the results are overestimated and show higher values;
- Calculations of areas and solar energy potential should consider tilt of the surfaces;
- The values are overestimated due to absence of cloud correction;
- There is no information about existing solar systems;
- Further improvement if GUI should be done.

Therefore, the shortcoming should be overcome with the future development. Furthermore there are some drawbacks that can be fixed with the next edition of the application. As for example the new dataset will be processed considering the cloud correction. Moreover, the information about the existing solar systems could be collected using the data from the installers. Along with it, the information about the aspect and slope will be included which

will allow to estimate the available areas more accurate. As far as the work with the user interface is concerned, it should be improved according to existing information collected during the questionnaire as well as the examples of the state-of-the-art.

Chapter 7

Epilogue

Web-based Solar Cadastre has been a topic of significant interest within the environmental community, urban planners, installers, authorities and property owners. LIDAR has emerged as an effective technology for the acquisition and generation of high-resolution 3D models from a remote capturing prospective. Based on the outcome of this technology, a methodology of data processing and data visualization could be established.

The following research was conducted in order to assist in decision-making process of solar panel installation. A feasibility and methodology for a Web-based Solar Cadastre, application were examined based on the methodology for photovoltaic assessment developed in collaboration of the Institute for Applied Remote Sensing and the Institute for Renewable Energy, EURAC Research. The Solar Tirol WebGIS was developed as an interactive instrument that can analyse and visualize solar potential characteristics, increase environmental awareness among residents and provide private users and authorities with comprehensive information for planning and installation of solar power systems in a intuitive environment running in a Web browser. Moreover, one of the concerns of this research is to develop an approach that allows storage of a limited amount of data, but performs various estimations. The Solar Tirol WebGIS is a client/server application that was developed using free and open-source software libraries, frameworks and current Web standards.

Generally speaking, the task of identification of suitable surfaces for solar panel installation is not trivial. First of all, to produce solar potential estimations many parameters must be taken into account, for example: azimuth, elevation, shadowing, sunlight intensity and climate impacts. Therefore, solar simulations based on high resolution DTM and DSM must be performed. The actual research was based on the input data produced by the r.sun module, an open-source component of GRASS GIS. The methodology for estimation of solar potential is validated by the Institute for Renewable Energy, EURAC, that performed the empirical work for it. The estimations are based on the two most usable and mature

photovoltaic technologies CdTe and pcSi. However, the application could be extended with other technologies if needed. The estimation of photovoltaic potential was done according to the algorithm described in chapter 3. Hence, the contribution of the actual study includes implementation of these methods within the Web environment using open-source solutions.

Based on the methodology, the data model was implemented in a relational DBMS with spatial extension. The PostgreSQL DBMS, and its extension for spatial data PostGIS, utilized for this had a host of benefits such as support of different data formats, spatial analysis and query operations, fast querying and retrieval due to its index system, and support of raster data which allows storage, indexing, querying, analysis and delivery of the data.

The WebGIS architecture was done according to a well-established three-tier architecture. The front-end (presentation layer) is incorporated in a Web Browser and the implementation of the layout and interaction is done in JavaScript, JSP and CSS. The software components used on the client are the JavaScript Web Mapping framework Openlayers and the GUI framework Ext.js with its extension GeoExt.js. OpenLayers is a generic mapping component, designed to consume spatial data and maps from numerous sources and display that data in a Web browser. The Ext.js framework comprises standard GUI components, including pre-built components for lists, panels, tables, and dialogues, whereas GeoExt.js adds some functionality to bind basic ExtJS GUI components to the spatial features of OpenLayers. The middleware (application layer) component uses Apache as Web Server, Apache Tomcat as Servlet Engine and Geoserver as a rendering engine. Geoserver is an open source server for sharing geospatial data. The data layer comprises the access to file data sets (raster or vector) and to the DBMS. The three-tier architecture provides with such benefits as performance, scalability, availability, security, reuse and easy maintenance.

Therefore, the Solar Tirol WebGIS application includes digital basemaps, operational layers, tools and a geodatabase. Furthermore, Google, Bing and Open Street Map APIs are used as base layers, where users can find the familiar interfaces of a street map, terrain or hybrid representation. The operational layers represent the information about insolation, cadastre data and protected areas. Therefore, the methodology was implemented in a way that a user could estimate the characteristics on-the-fly by identifying a feature from the digital map. The server-side component produces the estimations and sends the results to the client. The estimations are presented via a pop-up window with the corresponding information about irradiance distribution, electrical power, electrical energy, emission savings and photovoltaic output. Moreover, a user can retrieve additional information about the data (metadata) from the EURAC spatial catalog for each layer. The application provides a feedback form that offers the possibility for communication between a user and developer which can bring forward new improvements and fix the problems that users might face. The WebGIS Solar Tirol is developed within SDI EURAC that provides easy access for collaboration

and distribution of solar potential data, therefore the data could be shared via the portal of the Autonomous Province of Bolzano by means of Web services and metadata harvesting.

The Solar Cadastre WebGIS demonstrates the use of modern Web standards and development practices to create an interactive user interface for Web-based environmental modeling. For practical applications, Solar Cadastre can be used as a fast visualization for investigating solar potential at roof tops. The Web-based application gives a quick and easy way to perform evaluation of a solar system before turning to deep investigations provided by installing and planning companies. In addition, the Solar Tirol WebGIS is future-oriented system that could be scalable on the different areas of the application. Aside from that, the database could be changed, but the working principle remains the same. Moreover, the system could be enhanced with new operational layers if needed, that makes it flexible from the content point of view.

However, it is of paramount importance to remember that the application is enabled to provide approximate information. Therefore, the rough estimates of the solar potentials were calculated based on the models with some assumptions applied. They should be used for general consideration of roof suitability and further investigations on-site should be performed by experts in all cases.

From the research that has been conducted, the future workflow should consider several aspects. First, the application could benefit from an on-line calculator that considers user input for the estimation of photovoltaic characteristics. The Solar Cadastre WebGIS should also include the estimations of solar thermal potential, however due to absence of sufficient information as number of residents, living area and number of storeys; such estimations were not performed in the current research. Additionally, the cloud correction information should be taken into account to improve the results.

According to Kanters et al. (2014) the design of user interfaces is a critical component to the success and adoption of any Web application. Although Solar Cadastre was designed to be handy for people of different backgrounds, further study is necessary for better understanding of how the application can be improved. Eventually, support of mobile devices would be an issue of interest to improve field operations and make better informed business decisions.

In fact, the installation cost, monthly revenue and available installers could be information of high interest for many users. Based on this data, the decision for further work towards solar energy implementations can be made. In addition to that, the stakeholders could use it as underlying base for an improvement of energy policy.

Chapter 8

Appendix A. Requirements

Questionnaire for Solar Tirol WebGIS

8.1 Parameters

1. How should the following parameters be presented?

a) Irradiance

- ☐ monthly sum
- ☐ season sum
- ☐ yearly sum

b) Photovoltaic Potential

- ☐ monthly sum
- ☐ season sum
- ☐ yearly sum

c) Thermal Potential

- ☐ monthly sum
- ☐ season sum
- ☐ yearly sum

d) Climatic data

- ☐ Irradiance
- ☐ Temperature
- ☐ Linke atmospheric turbidity
- ☐ Cloud correction

e) Temperature

- ☐ monthly sum
- ☐ season sum
- ☐ yearly sum

f) More

- ☐ Horizon angle height
- ☐ Aspect
- ☐ Slope
- ☐ Savings CO_2
- ☐ Temperature of the module
- ☐ PV efficiency

g) Objects

- ☐ Historical objects
- ☐ Cadastre data
- ☐ LiDAR flight campaign
- ☐ Classification of building's applications

h) Statistical graphics

- ☐ Temperature distribution
- ☐ Irradiance distribution
- ☐ PV Potential distribution
- ☐ Thermal Potential distribution
- ☐ Module Temperature distribution

i) Solar Photovoltaic technology (-ies)

- ☐ Cadmium telluride - CdTe
- ☐ Polycrystalline silicon - pcSi
- ☐ _____
- ☐ _____

2. Download of the data. Please, other parameters according to your opinion.

- | | | |
|--|--|-----------------------------|
| <input type="radio"/> Irradiance | <input type="radio"/> Module Temperature | <input type="radio"/> _____ |
| <input type="radio"/> Temperature distribution | <input type="radio"/> _____ | <input type="radio"/> _____ |
| <input type="radio"/> Horizon angle height | <input type="radio"/> _____ | <input type="radio"/> _____ |

3. Please list the most relevant parameters from your opinion (starting from the most important one)

- | | | |
|----------|----------|----------|
| 1. _____ | 4. _____ | 7. _____ |
| 2. _____ | 5. _____ | 8. _____ |
| 3. _____ | 6. _____ | 9. _____ |

4. How should be aggregated information represented?

- ☐ at cadastral parcel
- ☐ at district level
- ☐ at settlement level

5. Please describe your personal requirements (e.g. data download, potential sites, cost for the owner, source-crowding)

8.2 Outlook

6. Parameters to visualize

- ☐ Buildings in 3D
- ☐ Solar potential of building facades
- ☐ Area m^2 under a roof surface
- ☐ Cost to Owner
- ☐ Average Monthly Revenue
- ☐ Installed systems
- ☐ A technical report, containing information about the Solar potential and the additional characteristics, should be available for a requested building.

7. Interactive tool for calculations can let users insert their parameters in order to estimate the energy consumption and benefits from the solar system installation (see figure 8.1) According to your opinion and experience, how useful is such an interactive tool?

Definitely ☐—☐—☐—☐—☐—☐—☐ It is not necessary

8.3 General information

8. Which sector of industry do you represent?

- ☐ Planning, Architecture
- ☐ Installation and maintenance
- ☐ Public administration
- ☐ Other, namely _____

Choose number of people and available area on the roof!

Number of people

Photovoltaics

Available area m² % usage

Consumption kWh/Year

Installed capacity kWp

Electricity production kWh/Year

CO₂ savings kg

Potential of Solar Water Heating

Size m²

Consumption Liter/Year

Energy production kWh/Day

CO₂ savings kg

Figure 8.1: Interactive tool for solar potential estimations

9. If your organization is involved in different PV-projects or sells different types of PV- systems, could you indicate what the PV-systems are used for?

- ☐ Productive uses: agriculture, rural/cottage industry, small business
- ☐ Community/social services: village water pumping, health centers, schools, etc.
- ☐ Solar home systems.
- ☐ Other, namely _____
- ☐ None

10. What type of working tool for data handling do you normally use? (e.g. Auto-CAD PV/Solar System Design)

- ☐ _____
- ☐ _____

11. Please write down the data format, which is the most convenient for you to use (e.g. .tiff)

- ☐ _____
- ☐ _____

12. Are you aware of Solar Cadaster Web GIS applications for South Tyrol? (e.g. Solar Cadaster Brixen - Bressanone)

- ☐ Yes, I use it.
- ☐ I only heard about it
- ☐ I have never heard before

Chapter 9

Appendix B. User Requirements Infographic

Solar Cadastre Workshop

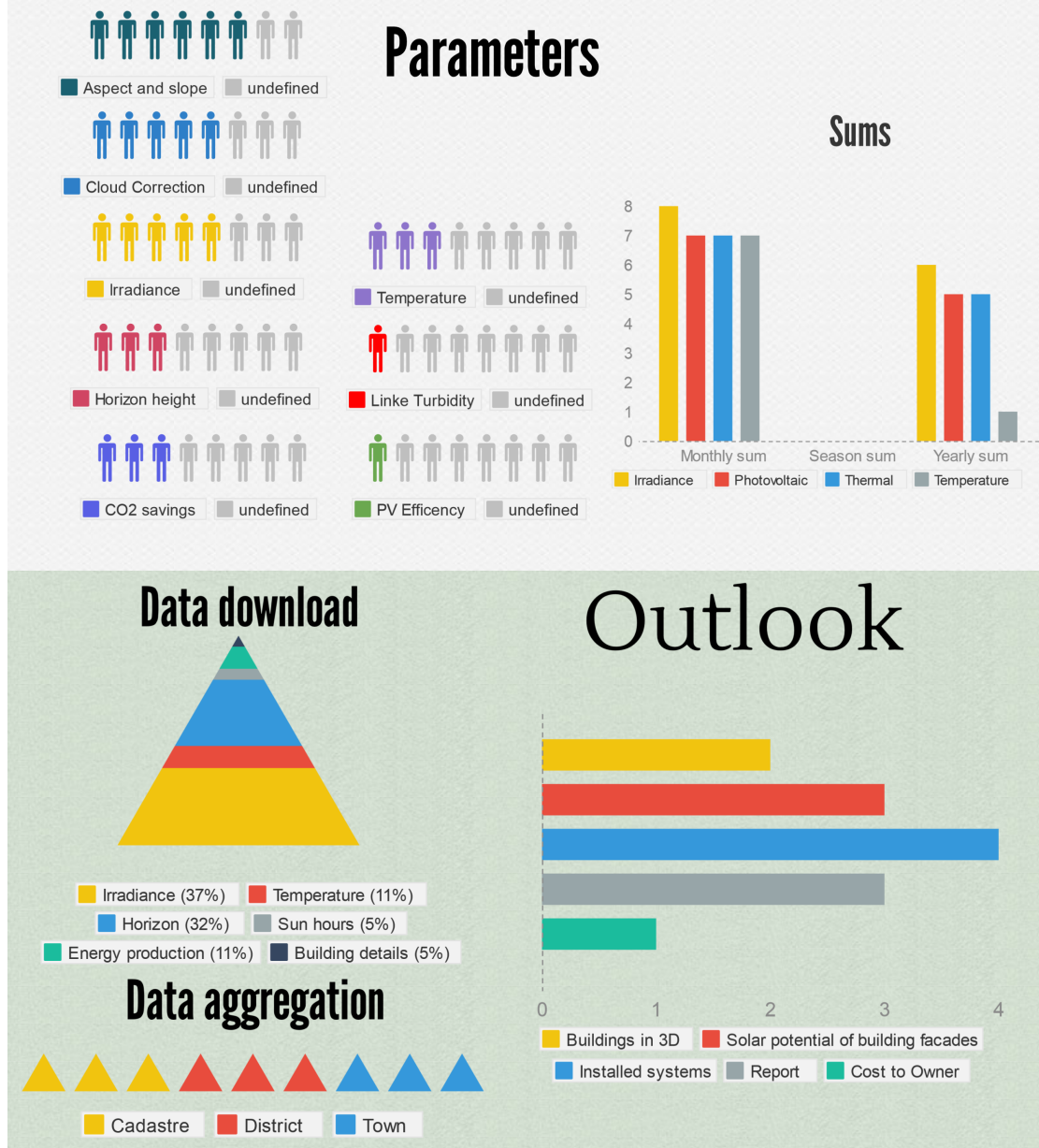


Figure 9.1: User Requirements Infographic

Chapter 10

Appendix C. Usability Questionnaire

i This feature is limited for free users. You can upgrade your account by following the instructions [here](#).

Results for: Solar Tirol Record No: 1

Assignment Please, read carefully the information in the welcome window, including the section "How to use". Check the structure of the application: overview map, map panel, toolbar, panels "Layers" and "About", toolbar, panels "Layers" and "About". Look through the available layers.

	1	2	3	4	5	Responses	Weighted Average	
Evaluation	0 (0.00%)	0 (0.00%)	1 (11.11%)	5 (55.56%)	3 (33.33%)	9	4.22 / 5	
							4.22 / 5	

Assignment Zoom in to a location by selection it on the toolbar. Chose Bolzano or Bressanone, or else zoom in manually; Once you have a larger scale, find a building on your choice. Zoom in, so that the details of a roof could be distinguished; Select a feature by left mouse click. The information window should pop up; Look through the information in the window; Take a look on all the sections of this window; Close the window; Measure the area and length of the selected feature by using the measuring tools from the toolbar; Export the map to PDF by choosing the print extend. Export the data into KML file.

	1	2	3	4	5	Responses	Weighted Average	
Evaluation	0 (0.00%)	2 (22.22%)	2 (22.22%)	3 (33.33%)	2 (22.22%)	9	3.56 / 5	
							3.56 / 5	

Assignment On the left side you can see the tree with the layers, legend and two symbols for each layer; Move the mouse cursor over the layer name and try to find if there are details about the layer available; Click on the pictogram with the magnifying glass. The map scale should be changed; Click on the pictogram with the piece of paper. Investigate the information in the appeared window. Find a link 'Show entire metadata' in the appeared window. Follow the link and open EURAC Geonetwork. Investigate the metadata.

	1	2	3	4	5	Responses	Weighted Average	
Evaluation	0 (0.00%)	3 (33.33%)	2 (22.22%)	2 (22.22%)	2 (22.22%)	9	3.33 / 5	
							3.33 / 5	

Usability test

	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree	Responses	Weighted Average	
I would use the Web GIS application if I planed the installation of the solar system in my own house?	0 (0.00%)	0 (0.00%)	0 (0.00%)	7 (77.78%)	2 (22.22%)	9	4.22 / 5	
I acquired all the needed information about the solar potential from the Web GIS	0 (0.00%)	1 (11.11%)	3 (33.33%)	4 (44.44%)	1 (11.11%)	9	3.56 / 5	
I am aware of the constraints in the solar potential estimations.	0 (0.00%)	0 (0.00%)	3 (33.33%)	2 (22.22%)	4 (44.44%)	9	4.11 / 5	
The application is user-friendly.	0 (0.00%)	1 (11.11%)	0 (0.00%)	5 (55.56%)	3 (33.33%)	9	4.11 / 5	
I had problems with the pop up window of the selected feature.	5 (55.56%)	0 (0.00%)	2 (22.22%)	2 (22.22%)	0 (0.00%)	9	2.11 / 5	
I am interested in the information about the dataset.	1 (11.11%)	0 (0.00%)	2 (22.22%)	3 (33.33%)	3 (33.33%)	9	3.78 / 5	
I like the user interface	0 (0.00%)	1 (11.11%)	0 (0.00%)	4 (44.44%)	4 (44.44%)	9	4.22 / 5	
The application is responsive.	0 (0.00%)	0 (0.00%)	2 (22.22%)	3 (33.33%)	4 (44.44%)	9	4.22 / 5	
I am satisfied with the user experience.	0 (0.00%)	1 (11.11%)	0 (0.00%)	6 (66.67%)	2 (22.22%)	9	4.00 / 5	
							3.81 / 5	

If you couldn't obtain all the necessary information, please list below what you would want to see in the next edition.

I am not working in the field, nor do I understand any of the functionalities or data. I don't think the tool is user-friendly enough for persons who are totally "ignorant" in the field.
- calculation of areas and Energy yield/solar energy potential on tilted surfaces
ok
highlighted feature should appear in a different color, with more contrast respect to the solar potential palette. The pop-up window shouldn't cover the highlighted feature. Average monthly sum: better annual SUM

I would like to add more functionality, namely:

integrated PV potential from an area
no
total surface square meters

Your suggestions about the user-interface.

The interface is very nice to see, even from a "layman" point of view :-). But with no introduction or previous explanation a layman cannot really use it!
<ul style="list-style-type: none">- I would appreciate some more information about available base layers in the welcome window- mark the selected area a bit more clearly
<p>If the magnifying glass next to the 'Solar potential' layer is clicked, the map zooms out automatically. However, data is not displayed at this scale. I found that to be slightly confusing - when I tried it the first time I thought that something isn't working.</p> <p>Also, I think it might be better to load the map on a scale where solar potential data is visible, when the website is first accessed.</p>
very nice but I think google physical layer is not needed. I would like that this app would be available for a wider area. The magnifier glass is not well placed, by this I mean that is often place in the main menu, the user can be confused by this.
ok

Please report the problems if they occurred.

3*

Assignment

....•Follow the link and open EURAC Geonetwork.

On IE 10 the Layer metadata popup appears with no content inside of it (neither the link). :(

"Click on the pictogram with the piece of paper. Investigate the information in the appeared window": no information appeared in the window, and no link to be opened.

- there is no background when exporting to pdf using google background
- there is very poor (low resolution) background when exporting to pdf using open streetmap
- sometime the legend is missing when exporting to pdf
- I could not enable (tick) the small box under building footprint
- general remark: the values in the pop up window are not correct, check the formulas!

It was not possible to create pdf

I couldn't export the map to pdf

Nella scheda informativa la prima voce ha 6 cifre dopo la virgola che sono tutti 0. forse sono inutili.

Le unità di misura e i nomi scelti per le grandezze non coincidono. Sentire moser su questo, ma a me sembra che kWh/m² non sia un'energia, al limite un flusso di energia o una densità superficiale di energia. Credo che voi abbiate già moltiplicato per la superficie e quindi credo si debba togliere quel m² (ma ripeto sentite moser)

Stessa cosa anche per le altre grandezze controllate che le unità di misura siano corrette

Nel grafico dell'annual irradiance ci sono troppi numeri dopo la virgola. sono inutili. Anche qui, siete sicuri di non aver già moltiplicato per la superficie (e quindi dovete togliere il m⁻²)

Quando misuri l'area il risultato è in m e non in m²

Non mi esporta in PDF: si apre il browser su una pagina che non esiste.

il kml non mi si apre correttamente

La lente di ingrandimento non funziona, o meglio fa uno zoom su tutta la regione e basta

Marcello

while browsing, layers panel and toolbars did disappear, and had to reload the application to see them back

Chapter 11

Appendix D. Workflow for Estimation of Solar Potential Characteristics within Solar Tirol WebGIS

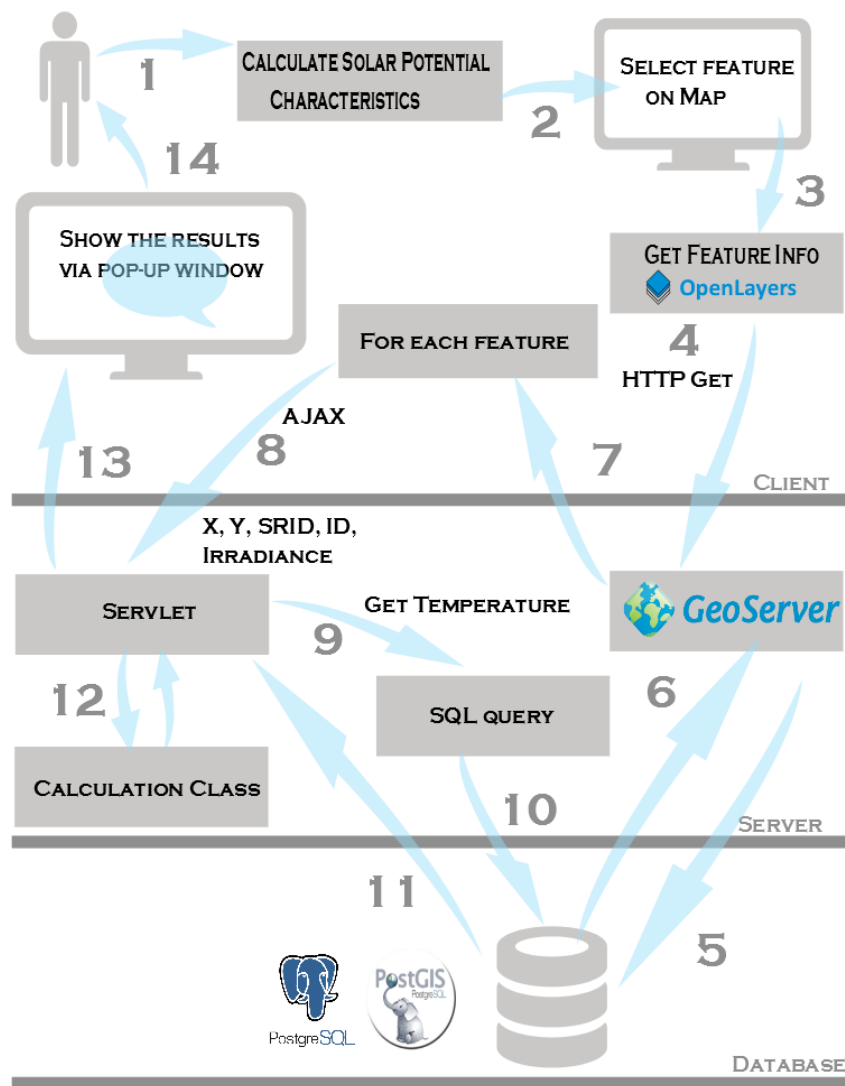


Figure 11.1: Workflow for estimation of solar potential characteristics within SolarTirol WebGIS. To estimate solar potential characteristics a user clicks on a feature. The action triggers GetFeature request (OGC) to Geoserver. The GetFeature operation returns a selection of features from the data source. For the each feature the parameters (coordinates, SRID, ID, irradiance value) are sent to the Server. The Servlet triggers SQL query with defined coordinates and SRID. The query requests a temperature value from the database according to the parsed parameters and returns corresponding values from the raster temperature table. Additionally, the SQL query simultaneously translates the projection. Therefore, the Servlet contains such parameters as irradiance and temperature. The constant values are the number of days and hours, module size, temperature of module cell and parameters of different PV technologies. The Calculation Class contains equations for estimation of efficiency, electrical energy, emissions savings and energy production. Hence, the estimations are performed in the Calculation Class based on the parsed parameters. The final results are parsed to the Servlet, which creates an JSON object and sends it to the client. Eventually, the results are visualized in the client component (Web browser) via pop-up window.

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