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Abstract:

The integrated Geospatial Urban Energy Information & Support System (iGUESS) is currently being developed as part of an EU project to reduce CO_2 emissions in five European cities. The project is intended to create a decision support platform providing access to distributed data sources and analysis and modelling tools through a single web-based interface. The final goal is to furnish the participating cities with current and projected space-time energy layers for their urban planning process. iGUESS provides access to tools that compute local renewable energy potentials and other spatially bound mitigation action potentials, like the construction of green roofs or installation of renewable energy technologies. These potential maps are fed into the non-spatial techno-economic assessment model ETEM to find the best combination of planning actions subject to a set of objectives (e.g. emission targets) and constraints (e.g. budget), helping urban planers deciding where, on what technologies and when to invest. The interoperability between models and data is guaranteed by the usage of the web service standards specified by the Open Geospatial Consortium. The main iGUESS interface for decision makers is a web-based GIS, which facilitates the spatial comparison of different model outputs. The system also provides a component for impact assessment by comparing the results of different scenarios and making use of spatial multi-criteria analysis algorithms. Another aspect of iGUESS is the incorporation of uncertainties associated with input data and modelling results into the decision support.

Keywords: Decision Support; Spatial Analysis; Energy Potential; Energy Modelling; WebGIS

1 INTRODUCTION

In 2007 the European Commission [2008] presented a long term Energy Policy proposal that included the reduction of CO_2 emissions by 20%, an increase of renewable energy to 20% of the energy mix and an increase in energy efficiency of 20%, all of this by 2020. Approved by the European Council months later, these goals have been translated into different plans at different scales by member states, in some cases targeting even more ambitious goals.

To comply with these plans, city councils contemplate today an array of new challenges and opportunities, managing building insulation, for instance, or accommodating the

growing availability of small scale renewable energy technology. Cities face a new level of urban planning decisions, that range from the city scale down to the building level. This process requires integrated analysis and decision support tools for energy planning, suitable for decision makers and urban planners, which are still largely lacking today [Denzer, 2005]. For different planning actions different data sources and modelling techniques are required. Further, cities must integrate their energy planning decision process into other national and European policies [European Parliament and European Council, 2007].

iGUESS pretends to aid this decision process, supporting the transition to a more sustainable and energy independent economy; its main goal is to identify the courses of action most effective in reducing CO_2 emissions. It is a product of the MUSIC (Mitigation in Urban areas: Solutions for Innovative Cities[1]) project, an effort by five European cities: Aberdeen in Scotland, UK, Ghent in Belgium, Montreuil in France, Ludwigsburg in Germany, and Rotterdam in the Netherlands. The project objectives include the introduction of energy as an additional layer in the spatial analysis process and aid translating this information into planning decisions. iGUESS meets these requirements by combining spatial information with energy models and decision support tools, and featuring an approachable and easy-to-use web interface.

This article describes iGUESS and the methods used in its conception. Section 2 digests the requirements collected and how they constrained the development of iGUESS; Section 3 presents the functional components and technological architecture of the system, and Section 4 details its Evaluation process; Section 5 closes with challenges and conclusions.

2 REQUIREMENTS AND DESIGN

Since stakeholders in the MUSIC project were already identified at the beginning of the project, and are geographically dispersed across five EU member states, each with particular expectations and needs, a requirements analysis [Hull et al., 2011] approach was adopted. This approach has been underpinned by three main strategies: (i) stakeholder interviews, (ii) requirement development sessions, and (iii) software prototyping.

During the initial phase, several interviews were conducted with each partner city. These included phone conversations and written questionnaires, based on which a list of requirements for each partner city was produced. These requirements formed the basis of an inventory of needs, a document that has been further refined with each stakeholder, as part of an on-going process.

The inventory of needs provided some guidelines and constraints for the development of the software. First, it became clear that iGUESS would have to be able to evolve as a decision support platform, integrating different assessment and modelling tools, some of which have yet to be developed. Users wanted to retain control of their data, so the system must be able to make use of distributed data sources, which led to the adoption of a service based architecture, both for data and processes. To make using and managing the system easier, and to facilitate access by the public, a web based interface was chosen. Finally, partially due to budget constraints, but mostly to promote project longevity, transparency and wider adoption in the future, a privilege has been given to open source technologies whenever new user interfaces or services have to be developed. These requirements made the basis on which the software prototyping phase started.

Twice a year, the partner cities (on a rotating basis) hold workshops for developers and

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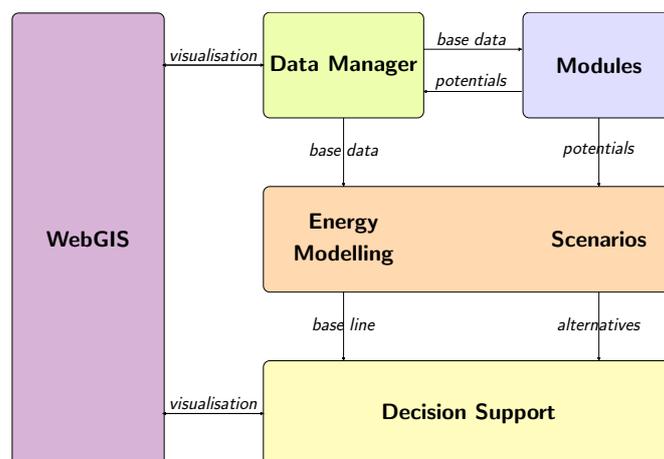
[1] http://www.themusicproject.eu/

Figure 1: The iGUESS user interface components.

stakeholders to discuss the progress in the development of iGUESS, data acquisition and availability, and to further refine project requirements.

3   THE INTEGRATED GEOSPATIAL URBAN ENERGY DECISION SUPPORT SYSTEM

This section describes iGUESS, starting with a collection of interacting functional components that composes its user interface, followed by the technologies that support it.

3.1   The web-based user interface components

Functional requirements were organised into five major domains or components, each consisting of a set of use cases corresponding to a particular step in the usage of iGUESS. These blocks also provided the main structure of the user interface: (i) Data Manager, (ii) Modules, (iii) Energy Modelling, (iv) Decision Support and (v) WebGIS (see Figure 1).

Data manager.   The primary information entity managed by iGUESS is the Dataset, a collection of values describing the spatial and/or temporal distribution of a particular variable. iGUESS deals with three basic types of datasets: (i) Spatial - describing variables or features distributed in space (e. g., elevation models, building footprints, roads, measurement stations); (ii) Time Series - sequences of values describing the time distribution of a certain variable (e. g., daily cloud cover, daily rainfall, energy demand); and (iii) Single Values - neither time nor space dependent variables used in calculations.

The Data Manager is dedicated to the collection and organisation of datasets, which are the basic inputs to the calculation modules; outputs of calculations are themselves datasets, stored and catalogued by the Data Manager. The user can perform several basic operations at this interface component: (i) Uploading and registering new datasets; (ii) Associating datasets with modules, by classifying them as specific module parameters (by designating a dataset as cloud cover, for instance, the user automatically associates it with the Solar Potential module); (iii) Uploading/registering new versions of existing datasets or discarding datasets no longer required; and (iv) Basic data visualisation, such as viewing a quick snapshot of a dataset.

Replication of spatial datasets is avoided by allowing users to register the address of a hosting server, using standard OGC services [Open Geospatial Consortium, 2011]. In this case the server must be able to provide spatial data as an image through Web Map Services (WMS) for web visualisation, and in GML through Web Feature Services (WFS) or Web Coverage Services (WCS) to feed the calculation modules.

Modules.   A Module is a routine that calculates new spatial datasets from a set of inputs. Since it can be a computationally intensive process, modules are run in a dedicated server that can be remotely invoked through the OGC Web Processing Service (WPS) protocol [de Jesus and Walker, 2011]. This server is presently harboured at the Data Centre of CRP Henri Tudor and shall later pass to the premises of one of the partner cities. The project partners are aiming to assemble a community of cities around the system to guarantee its continuity.

New datasets computed by a module characterise the potential of a particular planning action, identifying the areas of the city where its employment is more or less efficient. According to the requirements od the several project partners, the Modules being developed are: Solar Cadastre - to identify the most suitable areas to install photovoltaic panels; Geothermal Cadastre - to map the city subsoils and identify geologic conditions suitable for geothermal development; Urban Heat Island (UHI) - to identify locations in the city where the problem is most acute; Green roofs - to identify the rooftops where such structures can be installed; Fuel poverty - to characterise neighbourhoods with higher socio-economic vulnerability to high energy prices; Building stock - to help characterising energy demand at the building level

In iGUESS, the user is able to browse a catalogue of available modules, their required inputs, and the datasets they can create. For a given module, the user can build a configuration that assigns particular datasets to each required input; this requires the categorisation of datasets in specific input classes, denoted in iGUESS as Parameters. Parameters include classes such as *slope*, *height*, *roads*, *buildings*, etc. Once a module is fully configured it can be run, which spawns a new process on the processing server. When the module calculations are finished, the configuration is marked as run and the resulting dataset(s) are published by a Web Map Server and registered in the Data Manager.

Energy Modelling.   The Energy Modelling component is still in development and aims to be a tool for exploring different urban development alternatives. It first requires a Base Scenario, that characterises current energy flows in the city, modelling the city's infrastructure and energy demand. Adding expected technological and demand trends the Base Scenario projects the evolution of a city energy mix through time. A set of Indicators, such as CO_2 emissions per capita, or energy expenses per household, can then be used to characterise the scenario outcome. Base Scenarios are being developed for each city, compiling energy demand by sector using the ETEM model [Zachary et al., 2011].

From the Base Scenario, alternative scenarios can be built, for which the energy model can compute an optimal combination of actions subject to budgetary constraints. To do this the mode has to be fed with a set of Objectives, each concerning a specific Indicator, like minimising the consumption of fossil fuels, maximising renewable energy generation, or minimising energy poverty.

The datasets generated by the calculation modules will provide the constraints that bound the energy scenario optimisation process. A solar cadastre map, for instance, will provide the total photovoltaic capacity that can be installed in the city, plus the efficiency

(measured in terms of energy output per monetary investment) of each batch of solar panels. Scenarios will be compared with each other and to the Base Scenario using the various indicators they produce.

Decision Support.   The Decision Support aspect of iGUESS will help assess and visualise the socio-economic (fuel poverty, health) and environmental (air quality, urban heat island effect) impacts of different mitigation scenarios. These scenarios are composed by actions resulting from the modules output, e.g. green roof construction, wind energy technology installation.

To this purpose iGUESS will provide functionalities such as: (i) scenario comparison, (ii) spatial and temporal statistical aggregation and disaggregation services[2] to address multiple target scales (from building to city level), (iii) multi-criteria selection of optimal scenarios or actions, (iv) spatial and temporal optimisation of the renewable energy mix for each location in the city, also determining the best point in time for investment, (v) uncertainty management[3] to visualise uncertainties associated to scenario calculations, and (vi) report generation to prepare the results with maps, tables, and graphs in an manner understandable for decision makers.

WebGIS.   The system has to interact with data distributed across different sources: the initial inputs will, in most cases, be hosted by project partner cities, while the module outputs will reside in the iGUESS infrastructure. To provide context, users may wish to add other remote datasets such as those hosted by national administrations or European institutions. The WebGIS provides a single geospatial interface to all these data sources. Users can compare the outputs of alternate module configurations and can visualise the spatial interaction between alternative planning actions. They can also compare the outputs of alternative space-time scenarios, providing a fast and informal tool for quick decision assessment.

3.2   Technological architecture

iGUESS requires the coordination of several distributed services, each dedicated to a specific function. They are: (i) a database management system, (ii) a web map server, (iii) a web page server and a (iv) web processing server (see Figure 2).

The cornerstone of the infrastructure supporting iGUESS is the database management system (DBMS). It hosts the iGUESS database where all datasets and corresponding metadata are stored. The metadata not only describe the datasets but also the calculation modules, their associated configurations, and the energy scenarios. The technology chosen for DBMS is PostgreSQL[4], in combination with its geospatial extension PostGIS [Holl and Plum, 2009]. The database will be connected to a server providing Catalogue Services for the Web (CSW), another OGC standard; for this purpose, GeoNetwork[5] is being tested. The web map server provides spatial data over the world wide web (WWW) using the OGC standards previously mentioned: WMS, WFS and WCS. All spatial datasets managed by iGUESS are available through the map server, presently supported by MapServer[6].

Modules are wrapped by processing services compliant to the Web Processing Service standard, able to automatically publish outputs to the map server and register them in

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[2]http://www.uncertweb.org
[3]http://www.uncertml.org
[4]http://www.postgresql.org/
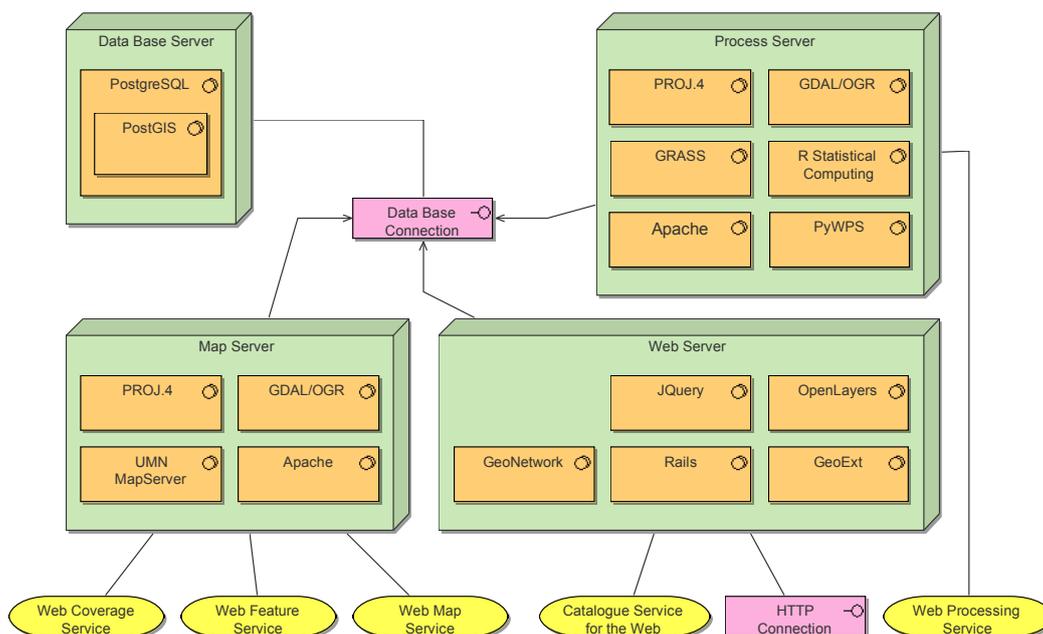[5]http://geonetwork-opensource.org/
[6]http://mapserver.org/about.html

Figure 2: The Tecnological Architecture supporting iGUESS. In green are nodes, in orange software, in pink connections and yellow for services.

the database. Of the several open source implementations of the standard, iGUESS is currently using PyWPS[7], based on the Python programming language (a versatile scripting language accessible to less experienced programmers). Various external third-party components will be used by the iGUESS web processing services, such as R [R Development Core Team, 2012] and GRASS GIS [GRASS Development Team, 2012] for space-time statistical analysis, PROJ.4[8] for spatial data reprojection, and GDAL/OGR[9] for data format conversion. PyWPS facilitates the interoperability with all these elements.

The iGUESS front end[10] is written in Ruby on Rails[11], a popular rapid application development framework. Using Rails provided access to a range of modern HTML 5 interface tools via the add-on library jQuery[12]. Web mapping has been leveraged on dedicated libraries: OpenLayers[13] for the client site interaction with WMS, WCS and WFS, plus GeoExt[14] for augmented WebGIS usability.

The web interface[15] functions as a remote client to the services provided by iGUESS. From their web browser, users have access to the map services and processing services that are part of iGUESS. Furthermore, using the metadata stored in the iGUESS database, users can create maps combining data on remote servers with that created by the various calculation modules.

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[7] http://pywps.wald.intevation.org

[8] http://proj.osgeo.org

[9] http://www.gdal.org

[10] The source code of iGUESS can be accessed at https://github.com/eykamp/iguess

[11] http://rubyonrails.org

[12] http://jquery.com

[13] http://openlayers.org

[14] http://geoext.org

[15] The test version of iGUESS can be accessed at http://iguess.tudor.lu:3000

4 EVALUATION

The general decision support systems evaluation framework proposed by Sànchez-Marrè et al. [2008] is being followed to evaluate iGUESS. In a first phase each calculation module plus the energy model are being assessed separately. The modules are being evaluated by comparing outputs with known measurements or similar tools; the solar cadastre module, for instance, was assessed against the low resolution outputs of the PVGIS model [16]. The geothermal model has been assessed against borehole measurements in different cities. In cases where result comparison is not possible a process of sensitivity analysis is applied; such as for the Urban Heat Island (UHI) module. Regarding the energy model, the separate evaluation is being made against historical data, but also comparing to the general energy trends provided each year by the IEA[17].

The evaluation of the interaction between components has been largely simplified by the usage to OGC standards, itself providing a well defined interaction framework. Small test cases were developed, each with enough data to run a single module, that can be used to assess the full process from data management, to potential calculation to energy modelling.

For the functional evaluation phase a different scenario is being developed with each city, focusing on those modules most relevant in its urban context. The results of these evaluation scenarios will be assessed through sensitivity analysis. A validation committee is being assembled, including urban planning experts from each city and academics in the field, that will supervise this phase. The final project meeting will gather this committee during two days for a final validation workshop.

5 CHALLENGES AND CONCLUSIONS

The first challenge that iGUESS is overcoming is the development of a common approach for each of the partner cities. This has been tackled through the systematic adoption of standard protocols that focus on integration and interoperability, making the system independent of particular methods or technologies. Another challenge is to combine the spatial nature of energy potentials with the non-spatial nature of the energy model. Resolving this issue shall require allocation algorithms, which are under development.

A further challenge is the storage of input data on multiple servers under the control of different institutions. This will require a monitoring mechanism to guarantee, or at least report on, data availability. Another issue imposed by the distribution of data sources is that spatial datasets are provided, for the most part, in local spatial reference systems. The strategy to overcome this issue is to demand the normalisation of all spatial datasets feed to iGUESS to the geodetic reference of the European Terrestrial Reference System (ETRS). This normalisation also facilitates the combination of iGUESS data with publicly available base layers such as Google Maps[18] or OpenStreetMap[19].

A system like iGUESS requires its interface to be easy enough for the non-technical user to understand and navigate, while also maintaining the complexity required by the nature of underlying tasks. This has been addressed in two ways: first by simplifying and thoroughly explaining the terminology, (with much input from the joint stakeholder sessions); and also by making use of familiar paradigms, such as the WebGIS.

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[16] http://re.jrc.ec.europa.eu/pvgis/
[17] http://www.worldenergyoutlook.org/
[18] http://maps.google.com
[19] http://www.openstreetmap.org

Starting with spatial potentials, iGUESS provides modelling tools to assess the impacts of mitigation actions in time and space, subject to objectives and constraints. This way, it provides stakeholders with an outlook of the energy trends in their cities, supporting the decision process in urban planning. These outlooks are further framed by an uncertainty assessment that informs stakeholders on the ambivalence of the modelling method. iGUESS thus offers an integrated interface and approach to the pipeline of urban planning process: data collection, data processing, modelling, uncertainty assessment and presentation of results.

iGUESS is a modular framework independent from the underlying models it hosts. While iGUESS is being built with energy related models, other models related to sustainable urban planning can be added to extend support for water, soil and air quality, as well as transportation and mobility. Since it is being developed in a distributed context, and is based on open standards, it will also be relatively easy to extend to further cities requiring an integrated tool for environmental modelling.

6 ACKNOWLEDGMENTS

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