A new open source DSS for assessment and planning of renewable energy: r.green

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Abstract

The spatially explicit Decision Support System (DSS) r.green, developed in the frame of the Alpine Space program recharge.green financed by EU, is able to identify the areas suitable for the installation of the main renewable energy systems based on criteria of sustainability and land conservation. The DSS is composed by a set of GRASS GIS modules r.green.wind, r.green.hydro, r.green.solar, r.green.biomassfor that deal with each specific renewable energy and r.green.impact that gives feedback on the impacts. Already available as a GRASS add-on, r.green can be used through Grass console or running the standard GUI within Grass or through QGIS.

Keywords

Renewable energy, wind, solar, forest biomass, hydropower, sustainability, Ecosystem services

1 Introduction

In the last decades, the importance of renewable energy is increasing in order to mitigate carbon dioxide emissions and to reduce the fossil fuel dependence of European Member States (Directive 2009/28/EC). Planning energy politics is one of the major task in present times, since energy availability is and will increasingly be crucial for the future well being and development of all the nations (Wirba et al. 2015, Martire et al. 2015, Michels et al. 2010). The growing demand for energy and in particular for renewable energy (RE) will increase the pressure on the environment and natural resources. The global economic crisis is exacerbating the problem especially in mountain areas that often guest fragile remnants of larger natural habitats. Both the demand for

renewable energy and the need for the conservation of biodiversity, soil, and connectivity transcend national borders and must be addressed at a transnational level. The recharge.green project was financed by EU in the frame of the Alpine Space projects with the core objective to develop tools and an integrated strategy for renewable energy production, sustainable land use systems as well as the conservation of biodiversity and soil across the Alpine region, so as to support the implementation of relevant EU Directives (recharge.green site). In this frame EURAC, DICAM-UNITN, CRA-MPF developed a DSS model that aims to help decision makers to deal with renewable energy planning. A plethora of DSS (Laquaniti and Sala 2009, Damiano et al. 2010, Wolfslehner and Seidl, 2010, Mari et al. 2011, Brown and Reed, 2012; Schwenk et al., 2012; Herzig et al., 2013; Sánchez-Lozano et al. 2013; Sacchelli et al., 2014; Verkerk et al., 2014; Wang et al., 2014; Sporcic et al., 2011) that deal with different topics is available nowadays in literature. The GIS based DSSs include spatial dimension thus adding a large amount of information and making the results of the DSS more understandable (Tognetti and Cherubini, 2009; Tattoni et al., 2011; Ayanu et al., 2012; Zambelli et al., 2012). Nevertheless, many of these DSS, especially those that deal with environmental issues, are designed to represent in detail a very specific theme and they often lack a multifunctional approach (Sacchelli et al., 2013a). In other cases these DSSs are designed to produce results at a macro-scale (national or macro-regional level) and they represent the phenomena using large pixel units, (square kilometers or more) thus they are not easily usable by local decision-makers and communities (Zambelli et al., 2012, Verkerk et al., 2014). However, the greatest limitation of these DSS is probably due to the fact that very few of them are really publicly available and therefore usable due to license restrictions or to actual availability from the authors (Frombo et al. 2009; Tattoni et al. 2010, Emer et al., 2011; Sacchelli et al., 2013a). In this way only the original authors are capable to reproduce the research that are described in the scientific papers, and this fact limits enormously the possibility to improve the DSS models and to share them. Thus, we developed a model with a multifunctional approach, designed to be applied not only at a macro scale but also at a very local scale and using an Open Source platform to overtake the cited limitations. The r.green model we developed is based on the GIS GRASS (Neteler et al., 2012), and was also developed taking advantage of python libraries and pygrass (Zambelli et al., 2013) and of QGIS to facilitate the creation of an user friendly interface. The software r,green was released as an add on of GRASS and is already available to be tested and improved, respecting the open source licences and giving proper credit to the original authors (Steinigera and Hay, 2009).

2 The model

The holistic spatially explicit Decision Support System (DSS) r.green is able to identify and quantify the areas suitable for the installation of renewable energy systems based on criteria of sustainability and land conservation. The aim of the creators and of the developers is to highlight Alpine biodiversity, land use patterns and related ecosystem services, and model the carrying capacity of

the Alpine ecosystems with respect to all aspects of RE production and consumption.
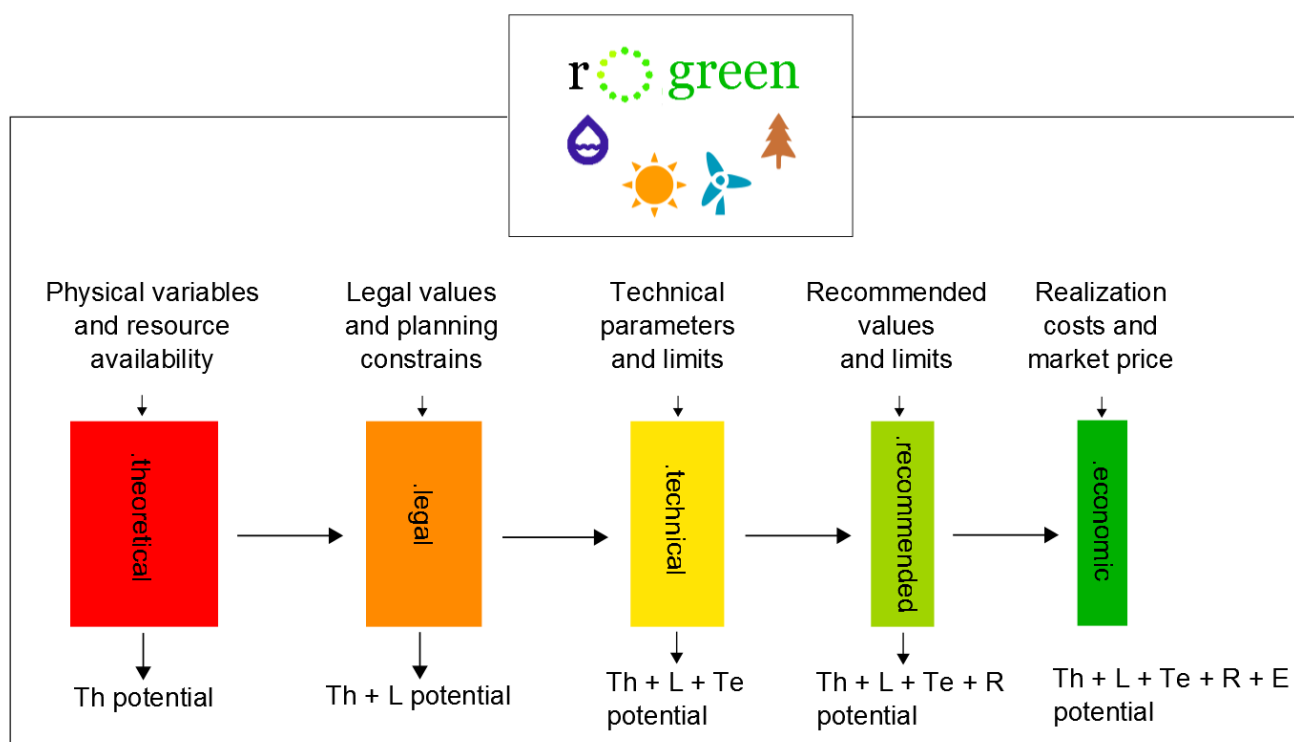
Fig. 1 : Sketch of the inputs and outputs of a possible scenario obtained with r.green. The logic steps that constitute the structure of the model are shown. Each sub-model follows the same logic structure.

The kernel of r.green resides within the GIS GRASS, and is composed by a set of add-on (additional modules) that can be run independently. Four main modules of the DSS, r.green.wind, r.green.hydro, r.green.solar and r.green.biomassfor deal with each specific renewable energy while the last one, r.green.impact, gives feedback on the impacts on the ecosystem services. Each module is structured by a set of sub-modules that represent a series of operational steps in an ideal flow of operations related to the level of exploitation considered. Each main module is composed by five sub-modules that were named theoretical, legal, technical, economic and recommended, as well as various modules specifically oriented to the analysis of impacts and assessment of the ecosystem services. The sub-module theoretical calculates the theoretical potential of the selected energy. The sub-module legal introduces legal constraints derived by plans or guidelines, the sub-module technical takes into account technical limits, the sub-module economic considers the economical convenience of the intervention and finally the sub-module recommended introduces the recommended parameters. The modules must be provided with a set of mandatory variables and a set of optional values. The more complete and accurate is the list of variables provided, the better the results.

All the run methodologies were used in four pilot areas: the Mis and Mae valley in the north east of Italy, the Triglav National Park in Slovenia, Leiblachtal in

Voralberg and the Gesso and Vermenagna Valley in the north west of Italy.

2.1 r.green.wind

Wind energy can help to cover the main peaks of energy consumption during the day. (Baban & Parry, 2001; Draxl & Mayr, 2011; Mari et al., 2011; van Haaren & Fthenakis, 2011) build a decision support system starting from wind velocity maps. The modules r.green.wind computes the energy potential starting from wind distribution functions and the power curve of available turbines (Draxl & Mayr, 2011 and Mari et al., 2011). The theoretical module considers the maximum limit to the amount of energy that can be converted in power, the so-called Betz limit (Bergey, 1979). The technical module needs the features of the wind-turbine (i.e. rated power, rotor diameter, hub heght, etc...). Output of the module are raster with the energy information (Mwh). The cost-benefit analysis, legal and environmental constrains can be considered in the other modules.

2.2 r.green.hydro

In the Alpine region, the main renewable energy actually used is hydro-power. Some authors ((Kusre et al., 2010; Palomino et al., 2013)) asses hydro-power potential using GIS. While Directive 2009/28/EC underlines the importance of renewable energies, one of the priorities of the Water Frame Directive (Directive 2000/60/EC) is the water protection. For this reason, the software r.green.hydro considers legal, technical, economic and sustainable principles of both the directives in order to evaluate the residual potential of rivers under different scenarios. Inputs of this module are raster files with discharge data along river network, digital terrain elevation model and vector files with existing plant position. The outputs of the model are two different vector files with theoretical available river segments, optimal position of the plants with their powers and their intakes and restitutions. In the legal module, we consider data on the minimum vital flows, the protected area, the maximum plant capacity, etc. Finally, we can derive the economic potential, i.e the market and the realization cost. This module let us to rank the feasibility of the plants on the bases of the cost. Notice that we consider all other geographical constrains (steepest area, distance from electricity grid, etc.) in the cost calculation.

2.3 r.green.solar

In the theoretical case we consider the Shockley & Queisser limit and the Carnot limit , while in the module r.green.solar.technical the efficiency of the solar cells can be added. The electricity is then computed according to european norm EN 15316-4-6. Mandatory input of the model can be the irradiation map, if not available it can be computed by using the GRASS module r.sun (Neteler and Mitasova 2008).

The different land use can be considered in the r.green.solar.reccomended in order to exclude area of particular interest. Also in this case, the economic module perform a cost-benefit analysis.

2.4 r.green.biomassfor

The characteristics of the Alpine region and the present forest landscape

dynamics suggest that the exploitation of wood-energy sources can be extremely important for bioenergy production. The module r.green.biomassfor is able to quantify in MWh/y the potential bio-energy exploitable from wood biomass in forest ecosystems in the light of ecological and economic sustainability. It was developed as an evolution of Biomasfor, the model that also inspired the structure of the other r.green sub-models (Zambelli et al. 2011, Zambelli et al 2012, Sacchelli et al 2013). The multi-step approach and the model's internal structure permit the use of heterogenous input dataset. To run the model a series of mandatory variables is required and the results can be utterly refined inserting a series of optional variables. The r.green.biomassfor considers theoretical, legal, technical, economic and sustainable principles to evaluate the energetic potential. The model calculates spatially explicit scenarios represented as maps and tabular data that can be queried and exported to other GIS and DSS models. The user can interactively change input data and/or variables (like for example mechanization level or chip wood price) thus producing different scenarios. The model can produce an estimate of a CO_2 emission and other multi-functionality parameters, such as fire risk and recreational evaluation.

2.4 r.green.impact

The present model contains also a module for estimating the economic impact of energy withdrawal on the ecosystem services (ESs). The overall objective of this module is to include the environmental costs and benefit into the computation of the exploitable energy quantity, in order to carry out cost-benefit analysis with environmental externalities. More precisely, the module considers the following ESs: timber and other wood products, carbon sequestration, hydrogeological protection and recreation. The fundamental input of the module is a vector file with the spatial definition of ESs economic values, typically a column for each different ES. The module automatically creates a raster map for each ES, based on the column´s name of the attribute table and calculates the change in the ES value considering a percentage of variation, which is different for each raster. This percentage can be edited by the user, based on the local characteristics and, if lacking, a default percentage is used.

2.5 Software interface

As declared in the software description, r.green is made by many modules and sub-modules, requires the input of many variables and its application may be very complex. Thus, the development of a graphic interface to open the software usability to non-specialist users was required.
 To facilitate this step we developed three possible ways to launch r.green through different interfaces and relative GIS:
i) through the link command of Grass console, recommended for advanced users
ii) running the standard GUI within Grass, developed using the Wxpython graphic libraries
iii) through a plugin of QGIS developed using PyQt and the Qt graphics libraries
A Graphic User Interface has been developed as a plugin of QGIS, a very user friendly open-source GIS software characterized by a logical structure very

similar to the most widely used GIS proprietary software. The QGIS plugin processes and exports outputs in standard formats (shapefiles for vector data, ASCII and GeoTiff for raster data).

Anyway to obtain the best and more reliable results our advice is to read the manual and to read the reports and the papers cited in the software description.

3 Tests

All the models were run in all the pilot areas but the most accurate tests were carried out in each pilot area selecting only the suitable energies.

The model r.green.hydro was mainly used in two pilot areas: the Mis and Mae valleys in the north east of Italy and the Gesso and Vermenagna valleys in Alpi Marittime Natural park in the north west of Italy. Different scenarios were performed., outputs of the module r.green.hydro are maps with energy production and relative costs. The maps were discussed in several meetings with stakeholders in order to plan the area through a participative approach. The module is also under tesitng by ARPA and Eaux Valldotanes for the Regione Autonoma Valle d'Aosta.
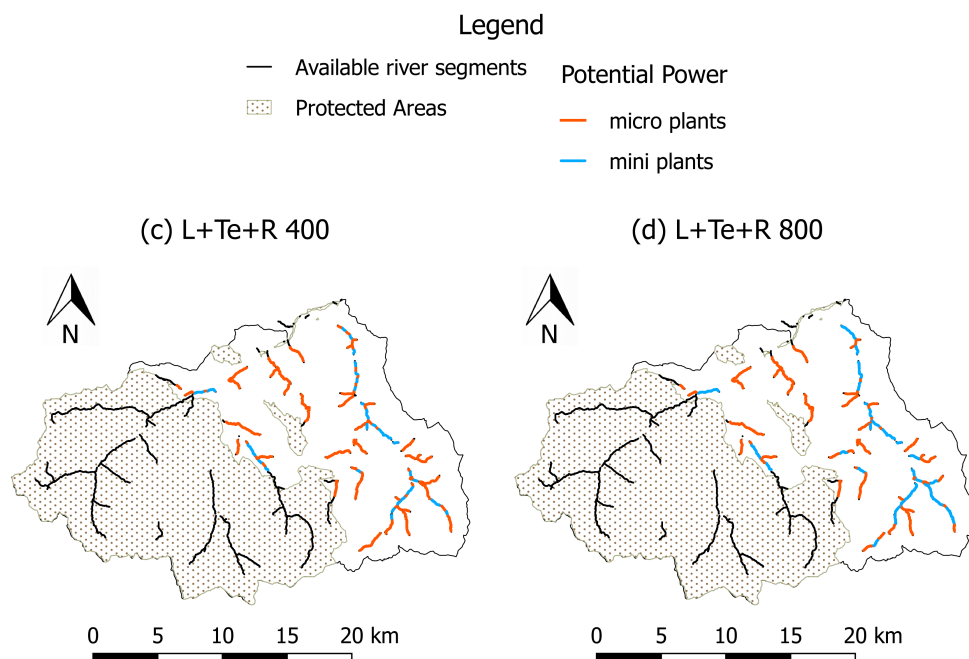

Fig. 2: Two different scenarios for hydro-power potential in Val di Gesso and Vermenagna (Piedmont, Italy) with different sets of plant lenghts

The models r.green.solar and r.green.wind were mainly used in pilot area of Vorarlberg/Leiblachtal, Austria. The region borders Germany in the North, Lake Constance in the West, and in the East and in the South the mountain Pfänder (1064 meters) forms a natural border.

The model r.green.biomassfor was used mainly in three pilot areas: the Mis and

Mae valley in north east Italy, The Alpi Marittime Natural park in north west Italy, and in the Triglav National Park in Slovenia. In Mis and Mae valley and in Alpi Marittime Natural park different scenarios with different wood chip prices combined with existing/planned bioenergy plants location were produced and showed to Regional administrators in different public events. This started a discussion on the optimization of bioenergy plants and in general on biomass opportunities. The model was used in meetings with local stakeholders of the Valleys. In Triglav National Park, different biomass production scenarios were created and a comparison with the Wisdom model previously used by the park managers to produce scenarios was carried out. Further details regarding the results of r.green processing in different Pilot areas are available in the documentation at the recharge.green site (http://www.recharge-green.eu/) and some of the results will be soon available for queries through the Jecami platform (http://www.jecami.eu/).
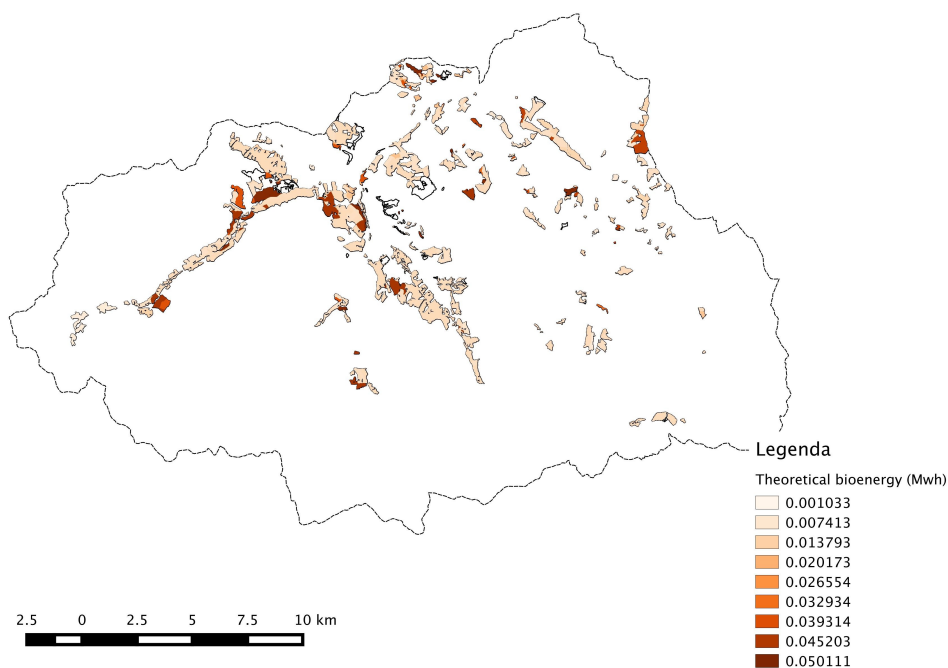
Fig. 3: A potential forest biomass scenario in in Val di Gesso and Vermenagna Piedmont (Italy), showing forest biomass residues potential in MWh per year. The potential is spatially explicit, this means that is calculated for each pixel.

4 Conclusions

The holistic spatially explicit Decision Support System (DSS) r.green is a very ambitious software. The first tests carried out in the frame of recharge.green project were more than encouraging, since the results of the model and of the submodels were used immediately with local stakeholders and decision makers. The models fostered discussions and produced scenarios that were judged plausible and useful. Thus the model is already usable as it is. However, the complexity of the topics treated by the model and consequently the

complexity of the software suggest that there is a large space for improvement, both on the point of view of logical procedures and on the point of view of software performances. The module r.green is available as an easy to install GRASS add-on and moreover it can be used through Grass or through the more user friendly QGIS software, thus facilitating usability for less experienced GIS user. The software is released with an open-source license to encourage further development and to spread and share knowledge and science.

Aknowledgments

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