BALANCING ALPINE ENERGY AND NATURE

2015

Modeling and visualization of optimal locations for renewable energy production in the Alpine Space with a special focus on selected pilot areas

recharge green

Alpine SPACE
EUROPEAN TERRITORIAL COOPERATION
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Alpine Space model

Pilot Areas

Editorial

Although the Alps have enormous potential for renewable energy (RE) production, there are many constraints to the expansion of RE technologies in the region. The Alps has a variety of protected areas that fall under different categories and classifications. Thus, one technology could be allowed in one protected area and prohibited in another. Because of the mountainous topology of the Alps, accessibility, and thus installation costs, adds to the complexities involved in locating RE production. Planning for the installation of new RE technology therefore needs to be very cautious and also to integrate economic, infrastructure, and environmental parameters.

The aim of the recharge.green project was to quantify RE potential in the Alps while ensuring that biodiversity and other ecosystem services were balanced. We developed two models that optimize the location of RE systems, taking into account topography, infrastructure, classification of the protected areas, and the economy of the supply chain from resources through to end-product delivery to the consumer. One model was developed at the Alpine level, and the other one for case studies at the local level. Though the two models or decision support systems (DSS) each have a different approach, they are complementary. They are geographically explicit, and were elaborated in close collaboration with different stakeholders, principally for the DSS case study part of the research.

The following chapters present the models, the assumptions behind them, and the key questions that they specifically answer. For each of them, the results have been uploaded to a user-friendly environment (JECAMI interface). Anyone can access this interface and can vary the main parameters impacting the location of RE sites in the Alps, while at the same time visualizing the consequences on a map. This interface is presented in detail for the two models to show what the user can expect and how to interpret the results.

F. Kraxner and S. Leduc

Alpine Space model

01

The results presented in the following should not be interpreted as being real-life outcomes. They are the results of modeling different scenarios, each with specific assumptions, and can therefore only be compared with results from the same model. For more information about the modeling and interpretation of the results, please contact the authors of the report directly.

Authors: Florian Kraxner, Sylvain Leduc, Hernán Serrano León

Methodology

WEB

BeWhere model
www.iiasa.ac.at/bewhere

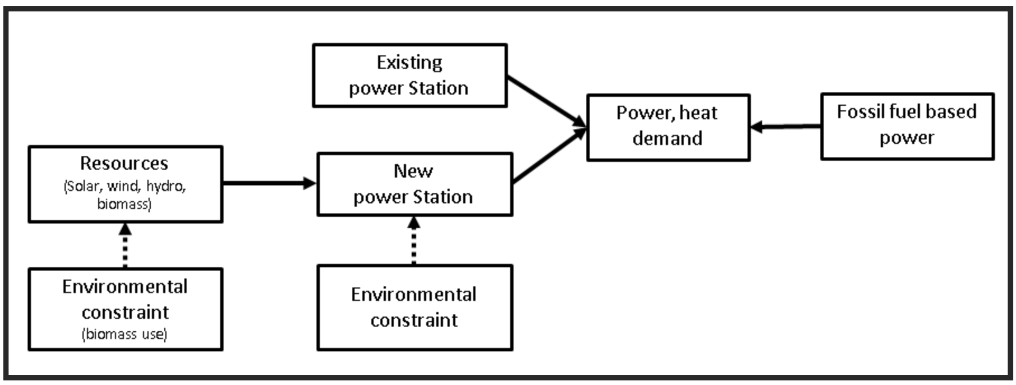
The Alpine Space DSS was built based on the optimization model BeWhere, developed at the International Institute for Applied Systems Analysis (IIASA), Austria. The model is a techno-economic, geographically explicit model that aims to identify the optimal location and combination of energy systems in a defined region. For the case of the Alpine Bow region, the model optimized the locations of wind farms, solar plants, hydropower stations, and bioenergy production plants. The demand for heat and power had to be met by existing industries, the new optimized production sites, and fossil fuel-based heat or power. The optimization of location aims for the welfare of the region studied. For bioenergy, for example, it includes harvest of feedstock, transport of feedstock to the production plant, processing of the feedstock into power and heat, delivery of power and heat to consumers, and also fossil fuel-based power and heat delivery. New energy production systems are selected once their production cost is sufficiently competitive with that of fossil fuel-based power or/and heat (see Figure 1).

The model is dependent on spatially explicit data that are as detailed as possible in terms of resources (i.e., solar radiation, wind speed, hydropower catchment, or biomass resources), energy demand (e.g., heat and power), and logistics (i.e., road and railway networks, power grid, and power stations). If the location of the renewable energy site identified is remote, then an additional power station can be set up and the power grid extended to that location. An environmental constraint with respect both to resources and production sites can be added to the above supply chain. Regarding the environmental constraints necessary to protect ecosystem services, limitations can be imposed on the extraction of biomass, and/or the setup of a renewable energy production site can be allowed or not allowed. For example, in a core region of a national park, no biomass can be collected and no production site can be set up, whereas in the buffer areas, some biomass can be extracted and solar panels—but not wind turbines—can be set up.

The model keeps track of the costs, emissions, and energy quantities of each segment of the supply chain. Therefore, for each scenario produced, the renewable energy potential, the power production cost, and the avoided emissions can be derived. Those three outputs are the final results provided on the JECAMI interface, along with the renewable energy systems locations and types.

FIGURE 1

The supply chain studied in the optimization model BeWhere.



BIOMASS

The bioenergy potential was estimated by the coupling of two IIASA models: the Global Forest Model (G4M) and the BeWhere model. The former estimates the increment of woody biomass under different forest management systems at a 1 km2 grid resolution. The latter is a techno-economic model that minimizes the cost of the whole supply chain and identifies the optimal geographical locations, capacities, technologies, and number of bioenergy production plants. Woody biomass is assumed to be used for power and heat purposes. It is shipped mainly by truck, and additional power and production plants can be built either within or outside the Alps where the demand for heat would warrant large facilities. The residual heat is assumed to be delivered to local district heating plants which brings extra income to the production plants, avoids spillover of valuable energy commodities, and increases fossil fuel substitution

Three different forest management scenarios have been identified from the G4M model: i) a business-as-usual scenario; ii) a high wood production scenario; and iii) a high carbon sequestration scenario. The BeWhere model is applied for each of them and a bioenergy potential is identified.

The results below present the latest results from the combined G4M and BeWhere models. First of all, the influence of the fossil fuel price on the biomasss used was analyzed. Figure 2 presents how the use of biomass can increase with an increase in fossil fuel prices. Having a fossil fuel price that is 25% lower than currently will allow the use of 60PJ of biomass, if all biomass is assumed to be available for energy purposes. Increasing the price of fossil fuel by a factor of 2.5 would approximately double the use of bioenergy under the same conditions. If one exludes the production of bioenergy and the extraction of biomass from protected areas (such as nature reserves, regional parks, UNESCO biosphere reserves or world heritage sites) then the potential would differ chiefly when biomass availability is restricted to below 50%. In that case, the potential decreases by one-half for all fossil fuel prices.

WEB

G4M
Global Forest Model
www.iiasa.ac.at/g4m

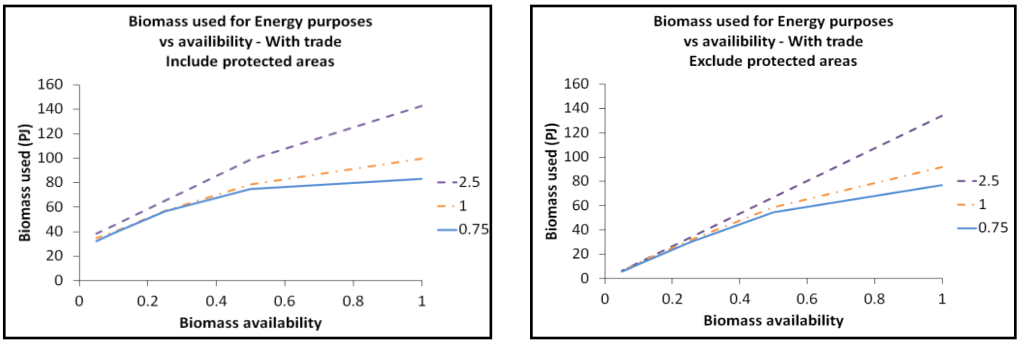


FIGURE 2

Biomass used for bioenergy conversion, including the protected areas (left) and excluding the protected areas (right).

HYDRO-POWER

The hydropower potential of the Alps is determined by integrating work done on by the European Academy of Bolzano (EURAC) and on the techno-economic model (BeWhere) from IIASA (Figure 3).

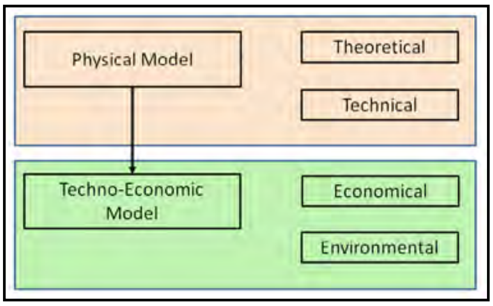


FIGURE 3

Overview of the approach for deriving the hydropower potential in the Alps.

EURAC derived the theoretical hydropower potential based on water precipitation and difference in elevation for each catchment (Figure 4 left). Based on the theoretical potential, it is assumed that catchments with a hydropower station already in situ, will not be included in the calculation of the economic and environmental potential (Figure 4 right). The BeWhere model was adapted for setting up hydropower plants based on the minimization of the complete supply chain. Power demand has to be met by existing hydropower stations and fossil fuel-based power. If the setup and power production of new hydropower stations are economically competitive, then a new hydropower station will be set up. A carbon tax can also be added, which enables the emission substitutions of the fossil fuel-based power production to be taken into account. In that way, the emission factors of each country are considered, as also are different power prices, setup costs, operation and maintenance costs, accessibility to power lines, and access costs The economic potential is derived from the BeWhere model at the catchment level. The locations of the hydropower plants are tracked in terms of the location of the protected area. There are six protected areas considered: special protection areas, natural parks, nature reserves, regional parks, UNESCO biosphere reserves, and UNESCO world heritage sites. Figure 5 presents the optimal locations of hydropower stations derived from the BeWhere model, taking into account their capacity and their location inside or outside a protected area for two scenarios. The first is a business-as-usual (BAU) scenario, and the second is a high carbon tax (50EUR/tCO2) scenario. For the first, the hydropower stations are spread out all across the region and have different capacities; for the second, the hydropower stations are mainly located toward the

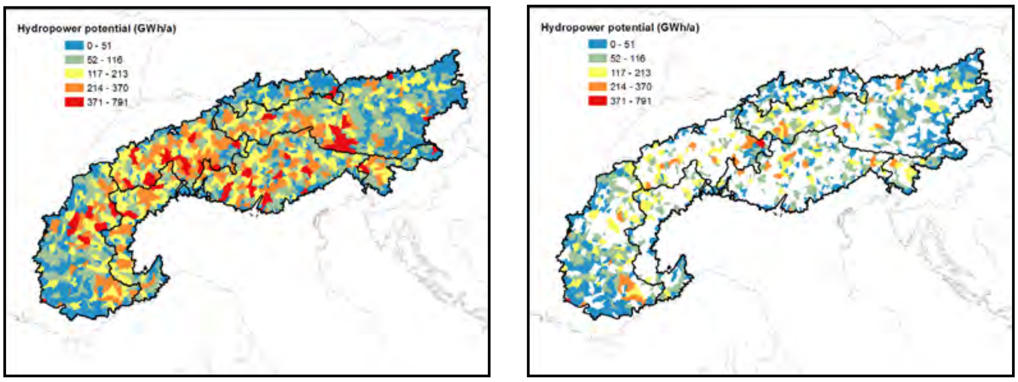


FIGURE 4

Theoretical potential of hydropower (left) (source: G. Garegnani et al. 2015) and feasible potential (right) where catchments with existing hydro power stations have been removed.

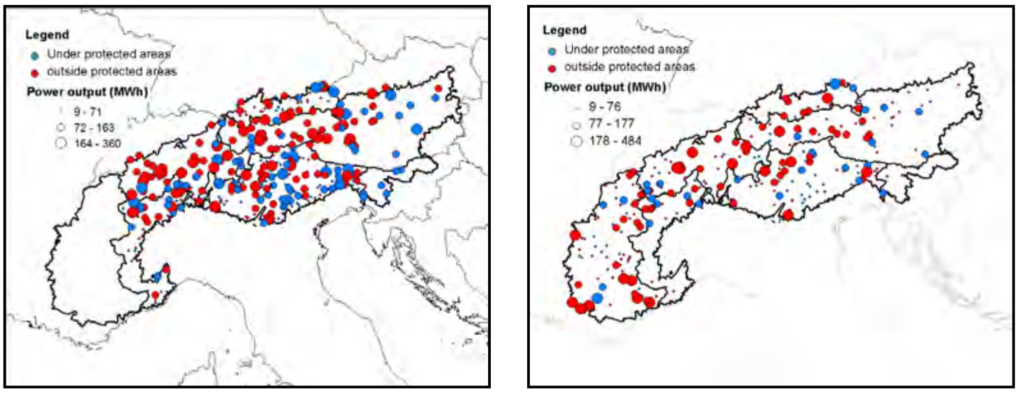


FIGURE 5

Example of results of the hydropower stations in the Alps for (left) business-as-usual scenario and (right) high carbon tax scenario.

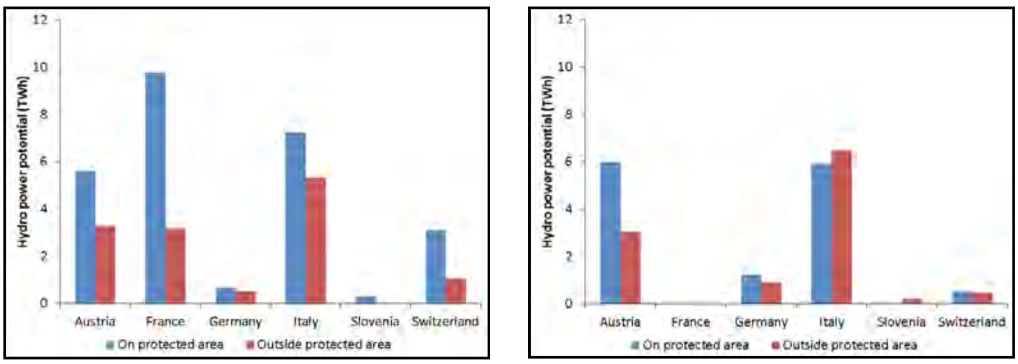


FIGURE 6

Results from the hydropower potential in the Alps for a (left) business-as-usual scenario and (right) high carbon tax scenario.

middle of the Alps. If a carbon tax is set in the system, the model forces costs to be minimized, mainly in regions where there are high carbon emissions. In this example, France is free of new hydropower stations, as its energy mix is based on hydro and nuclear energy, and it therefore emits less than neighboring countries. In this example, power cannot be traded between the Alpine countries. The results thus emphasize how it is possible for new policy applications to be sensitive to the distribution of RE systems.

Based on the maps obtained above, the economic potential can be derived if one considers the location of the plants within or outside protected areas (Figure 6). The potential can reach 40 TWh in the BAU scenario, but considering that new power stations can only be built outside the protected areas, the environmental potential will decrease to 12.5 TWh, which would increase actual production by 10%. A similar pattern is observed in the second scenario where the potential outside the protected areas would reach some 10TWh.

Note that these results are subject to change as new input data on power station setup costs, operation and maintenance costs, and power distribution costs are gathered.

In these cases the potential was only considered in terms of the location of the protected areas. Bear in mind that more ecosystem services need to be included in this study, and that as this is done, the potential could decrease accordingly. The age structure of the existing power stations also needs to be included so that decisions can be made on whether those stations should be renovated. The power output of those stations could certainly increase, without new ecosystems needing to be altered.

SOLAR AND WIND POWER

The solar and wind databases have been calculated by EURAC based, respectively, on irradiation and wind speed maps (see Figure 7 and Figure 8). The two maps present the theoretical potential without restriction in terms of landscape and accessibility.

For solar power, it is assumed that large solar (photovoltaic [PV]) panels can be installed in fields. The dedicated area for solar panels is then important. It is assumed that the solar panels can be located on south-facing slopes and that they do not encroach on forest land.

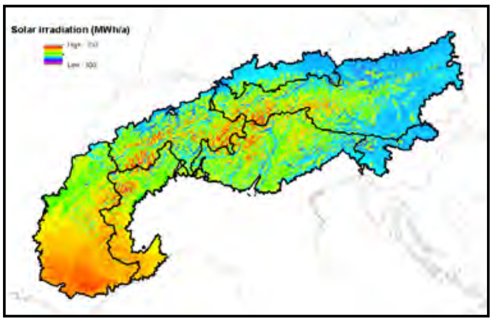


FIGURE 7

Solar power potential in the Alpine region (source: G. Garegnani et al. 2015).

The location of wind turbines on mountain crests or plateaus is a very sensitive topic among local communities and power manufacturers. Figure 9 shows the aggregated results from the theoretical potential. It is interesting to note that the potential is cut by a factor of two if the protected areas are not allowed to be used for wind turbines.

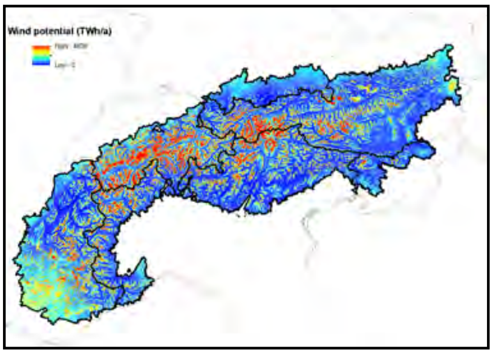


FIGURE 8

Wind power potential in the Alpine region (source: G. Garegnani et al. 2015).

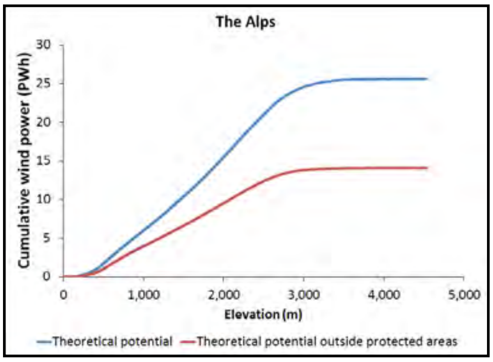


FIGURE 9

Profile of theoretical cumulative wind power potential with regard to elevation for the all countries of the Alps.

PROTECTED AREAS

To ensure nature conservation and avoid conflicts arising from the expansion of renewable energy, the diversity of protected areas was considered to assess their potential for renewable energy. To ensure nature conservation, some strict protection categories limit any human use, while other protection models pro mote a flexible integration of social, economic, and environmental objectives, where there is reliance on the interaction between nature and traditional lifestyles. Many of these areas allow for the use of local renewable energy sources compatible with nature conservation, exemplifying sustainable integration of local renewable energy use and the safeguarding of ecosystems services.

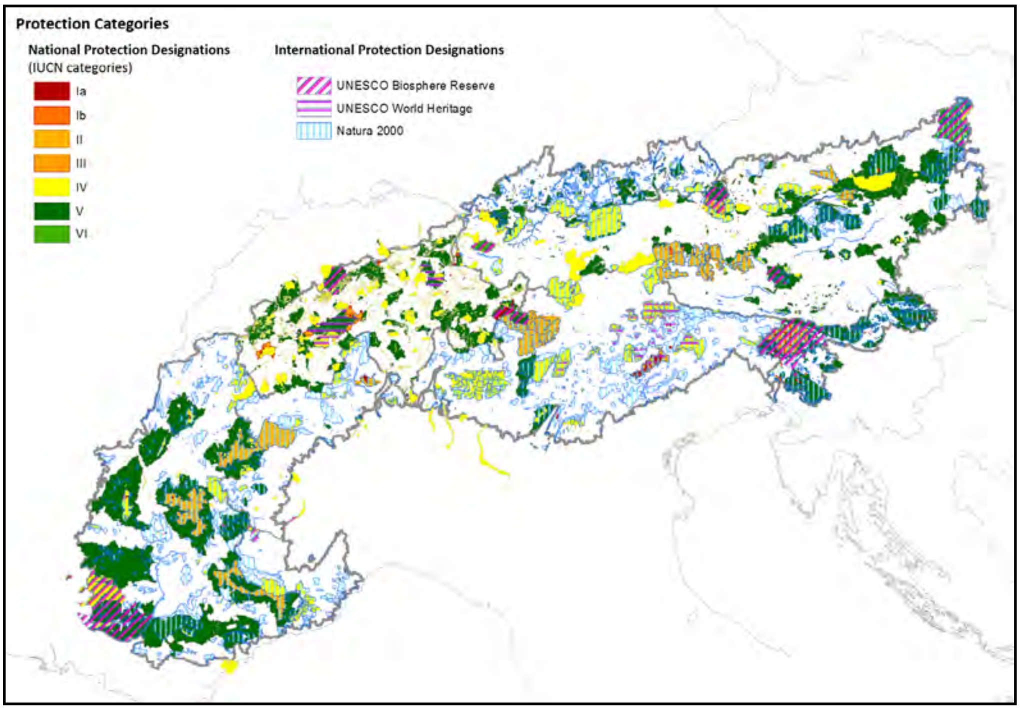


FIGURE 10

Overview of the protected areas and IUCN categories.

However, definitions of protected areas vary between countries and even between regions of the same country. Despite similar designations at national level (national parks, nature reserves, nature parks, regional parks, landscape protection areas, etc.), there is no consistency between the designation and the management objectives of the protected areas. Given the complexity of protection designations, model assumptions regarding protection constraints needed to be harmonized to enable transboundary decision making. Increased coherence between protected areas across national boundaries will provide a better basis for best practice management. In an attempt to harmonize the different protected area management approaches, the International Union for Conservation of Nature (IUCN) provides a global system of protected area categories (Figure 10). The seven different protected area categories (categories I to VII) are based on their primary management objectives; however, this classification does not imply a simple hierarchy in degree of intervention or naturalness. This unified system of protected area categories is independent of national designations.

The relationship between the international protection designations such as UNESCO sites (biosphere reserves, world heritage sites) and the Natura 2000 network, on the one hand, and the IUCN-protected areas, on the other, is not clear, and the UNESCO and Natura sites do not come under the IUCN definition of protected areas. The UNESCO sites were assumed to have been assigned a highly protected core zone similar to categories I–IV to ensure the long-term conservation of the values of the site. This core area is surrounded by a sustainable management buffer zone corresponding to category V or VI. The Natura 2000 network is formed by the Sites of Community Importance and Special Protection Areas designated under the Birds and Habitats Directives of the European Union. The main objective of Natura 2000 is the conservation of targeted species and habitats of European interest, which would correspond to protected areas under IUCN categories I to IV. Never-

TYPE OF PROTECTED AREA	NONE		LOW		MEDIUM		HIGH	
Protection scenario	Low	High	Low	High	Low	High	Low	High
Solar PV [1]	0.1	0.05	0.05	0.025	0.05	0	0	0
Wind turbines [1]	0.1	0.05	0.05	0	0.05	0	0	0
Hydropower station [2]	1	1	1	0	1	0	0	0
Biomass production plants [3]	0.75	0.5	0.5	0.25	0.25	0.1	0.1	0

[1] share of the area that may be dedicated for solar PV or wind mills.
[2] 0 means no hydropower station should be built, 1 means that a hydropower station may be built.
[3] share of the yearly biomass increment used for bioenergy production.

TABLE 1

Overview of the assumptions on the levels of protected areas for each of the technologies.

theless, the Habitats Directive also provides the opportunity for sustainable development management in participation with local communities and other stakeholders, corresponding to the approach of IUCN categories V and VI.

Each protected area designation was reclassified for each scenario according to the different levels of renewable energy production. The protected areas are defined in terms of three categories: low, medium, and high protection. New energy systems can be set up with some restriction within those areas, ranging, for example, from installation of a small hydropower plant in areas with low levels of protection to a total restriction on biomass intake in a very strictly protected environment. In addition to protection constraints, elevation is another constraining factor to the setup of wind farms or solar PV plants. Under a low environment constraint scenario, it is assumed that no wind turbines and solar PV plants can be set up above 2,000 m above sea level, whereas in a high constraint scenario, it is assumed that the same energy systems cannot be set up above 1,200 m. On the other hand, a hydropower station can either be located in a low protection scenario (except for highly protected areas) or completely prohibited in a high protection scenario. Finally, biomass collected can be harvested to a certain threshold in each type of protected area. The environmental protections are thus different for each technology and for each category of protected area (Table 1).

Because running the existing model and correctly interpreting the results is too complex for non-experts, the DSS is not available online for individual use. Instead, only a few of a huge number of scenarios are selected, (the ones that differ most with each other) and their results are presented on the JECAMI interface. The DSS results are presented in such a way that the user can run the DSS for either one renewable energy system (i.e., PV Solar, wind turbines, hydropower stations or bioenergy production plants) or all four renewable energy systems. The user can vary three parameters:

i) the cost of fossil fuel. The fossil fuel is the reference system, and if the cost of setting up new production plants is competitive enough compared to the cost of fossil fuel-based power, then new renewable energy systems will be selected.

ii) Carbon cost: the carbon cost is applied to any emission occurring along the supply chain. The higher the emission, the higher the cost will be.

iii) Environmental protection level: both a low and a high environmental protection level can be chosen.

The final results visualized on the JECAMI interface present the final potential, starting from the theoretical, technical, environmental, and economic potential. In the JECAMI interface, different layers can be superimposed on each other (e.g., path of species or occurrence of species) with the results from the pilot areas or the Alpine level.

JECAMI interface

The results from the model are uploaded to the JECAMI interface (www.jecami.eu). JECAMI does not allow the model itself to be run; however, it does allow the results that have been run at an earlier stage to be visualized. Using this interface, the user can choose different layers, such as the boundary of the Alps, protection areas, topography, etc. As well as the layers, the user can select different tools focused either on biodeversity (CSI Analysis, SMA calculation or Superspecie application) or RE potential (Alpine Area r.green or Pilot Region r.green).

The tool “Alpine Area r.green” allows the user to visualize the results from the BeWhere model at the Alpine Space level. The user is able to vary three parameters: i) fossil fuel price (as a factor of the based present from 2013); ii) a carbon cost; iii) level of environmental protection (high or low). The values from the fossil fuel price and the carbon cost depend on the technology selected. For each of those parameters, the user can choose one of the four RE technologies studied (i.e., bioenergy, hydropower, wind, or solar power) or a combination of all four. For each scenario, the location of the chosen technologies will be presented on the map based on the results from the BeWhere model. Together with the location, the user can also obtain information on the amount of RE produced, the magnitude of emissions, and a production cost for the selected technology for each specific scenario (see Figure 11).

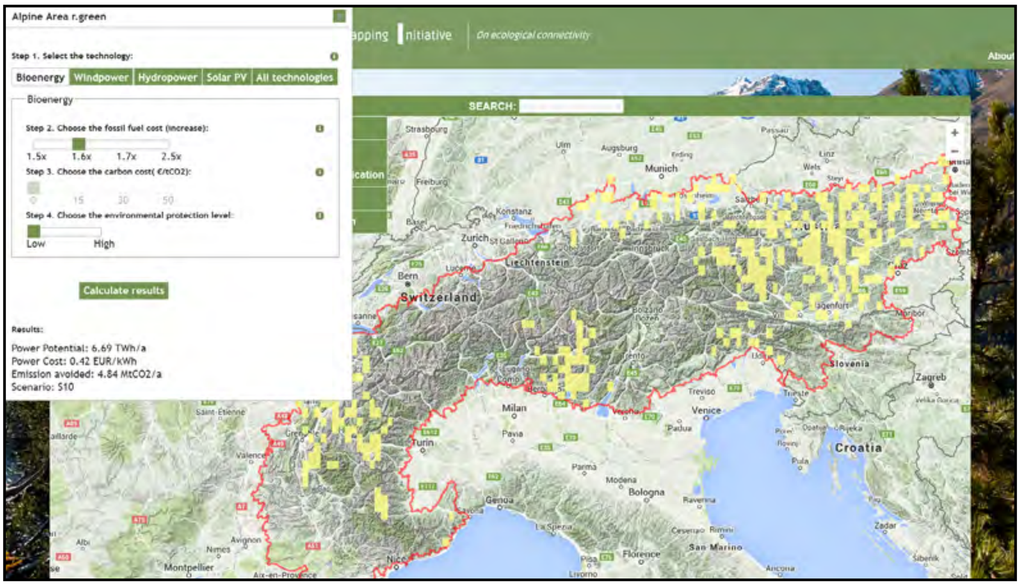


FIGURE 11

Screenshot of the results from a bioenergy scenario with a fossil fuel factor equals to 1.6, a low environmental protection level and no carbon cost.

Discussion

The results from the recharge.green project show that renewable energy strategies for the Alps must be carefully developed and based on high-resolution geographical information. Which of the technologies (bioenergy, wind power, hydropower, or solar) has the best fit to a given region or community, depends very much on the ultimate local objective: for example, is the primary objective, i) to protect landscape, scenery, or other ecosystems services for tourism or the local population; ii) to reach energy autarchy based on low-carbon targets; or iii) a combination of the two. Multiple objectives require special assessment methodologies and tools such as those developed and provided publicly by the recharge.green project. On the Alpine scale, it can be concluded that under pure cost minimization assumptions, strategies and policies in favor of solar and wind technologies would be desirable. However, detailed local optimization toward specific objectives might also favor technologies such as bioenergy and hydropower.

Pilot Areas

02

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Strategical environmental assessment

Renewable energy is an economic sector in which the interaction between human needs and natural resources exploitation is clearly evident. Intensive land use and natural resources depletion frequently occur when planning the increase of renewables, if the consequences of the management strategies are not carefully investigated. The strategic environmental assessment (SEA) is a useful tool for anticipating the effects of new power plant within a territory (Figure 12). In the case of forest biomass use for bioenergy the interactions between the human need of energy and natural resources are particular important, because the effects are visible not only with negative consequences on its resilience and its biodiversity. In addition, the capability of the forest of protecting people against natural hazards, such as landslides and rock falls, may be negatively affected. To take into account these possible effects, SEA represents an important anticipation tool. Although the environmental aspects of the plans and programmes are of particular concern, they are not the only sphere of interest in the SEA. The SEA procedure is applied also to foresee the impacts of the planned activities on the society, on human health and on the social sphere of the affected territory. The European Directive 2001/42/CE foresees a series of criteria

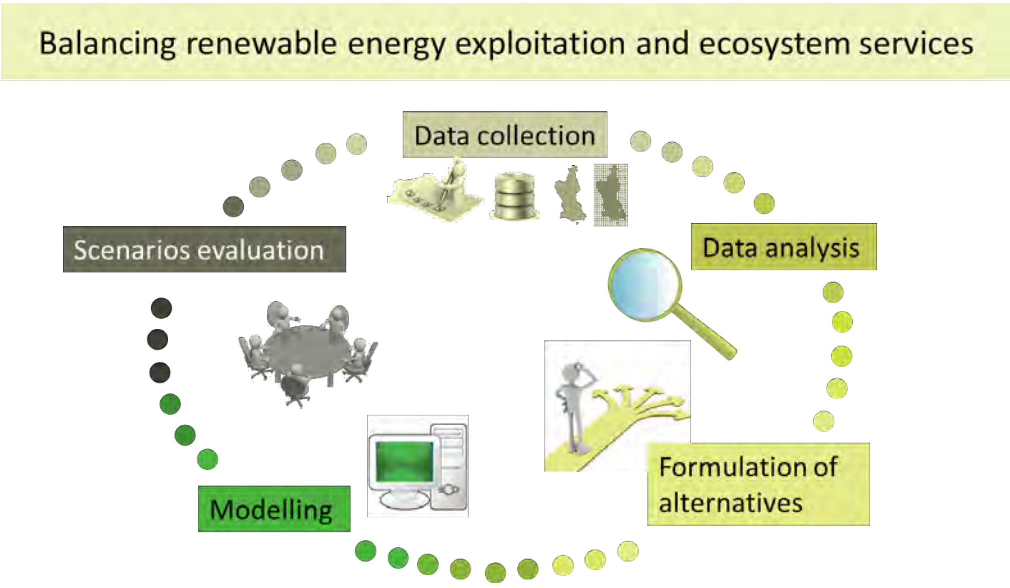


FIGURE 12

The steps for implementing a SEA procedure.

when planning the construction of a wood power plant, but also when collecting fuelwood from forests. Harvesting forest biomass produces both positive and negative effects. Concerning the positive consequences, collecting wood reduces fire risks within the forest and contribute to the aesthetic beauty of the forest, because cleaning forest path from dead wood and residuals give the idea of a well-kept environment; moreover, using wood for energy contribute to reduce the CO_2 emissions. On the other hand, forest biomass withdrawal depletes the soil fertility of the forest that the SEA procedure should consider:

- the probability, duration, frequency and reversibility of the effects;
- the cumulative nature of the effects;
- the trans-boundary nature of the effects;
- the risks to human health or the environment (e.g. due to accidents);
- the magnitude and spatial extent of the effects (geographical area and size of the population likely to be affected);
- the value and vulnerability of the area lvikely to be affected due to:
  - special natural characteristics or

cultural heritage;
  - exceeded environmental quality standards or limit values;
  - intensive land-use;
- the effects on areas or landscapes which have a recognized national, Community or international protection status.

The Directive describes the indicators to be considered but it does not suggest a specific procedure, so both in the literature and in the real applications the methodologies highly vary from case to case. Despite the high variability of approaches and considered variables, all the implementations of the SEA procedure share the same objective, aiming at comparing alternatives in order to understand the most viable and effective for the future development. Within this context, a decision support system (DSS), such as r.green, represent a useful tool for implementing a SEA for the energy sector and to account for the environmental impacts that new power plants and wood collection may generate. The approach that we use for the SEA is a 5 step procedure, as described in figure 1, in order to address the prescription of the Directive:

- Data collection;
- Data analysis;
- Formulation of the alternatives;
- GIS modelling;
- Evaluation of the scenarios.

In order to show the procedure, we provide a case study from the Gesso and Vermenagna valley (Italy). The study area of Gesso-Vermenagna (44° 15′ 00″ N, 7° 32′ 00″ E) is located in the north-western part of Italy (Piedmont Region) close to the French border. The territory includes seven municipalities (Valdieri, Entracque, Roaschia, Roccavione, Robilante, Vernante and Limone Piemonte) and a population of 10,022 inhabitants with a density of 0,194 inhabitant/ha (year 2010). The land area is approximately 51,500 ha of which about 32.000 ha are situated in protected areas (Maritime Alps Natural Park or Nature 2000 sites). The main land uses are forests (42%) and pastures (33%). Regarding the ownership about 45% are public forests while the remaining 55% are private forests. The main forest types are the European beech forests with 11.500 ha and the chestnut forests with 2.700 ha, and mixed forests with maple, linden and ash. The average standing stock is 183 m3/ha with some important differences among forest types: 245 m3/ha in chestnut forests, 156 m3/ha mixed broadleaved forests and 149 m3/ha in European beech forests. The average annual increment is 7.73 m3/ha year and a harvesting rate that varies depending on the forest types: 45% of annual increment in European beech and mixed broadleaved forests, and 80% in chestnut forests.

The environmental impacts are assessed considering the variation of the natural capital value in the area. Since taking out biomass from forests has an impact on several ecosystem services, the underlying idea for implementing the SEA procedure is that the more biomass is used for energy and the higher is the impact on the environment.

DATA COLLECTION

Data were collected with the aid of the Alpi Marittime Natural Park representatives. In order to apply SEA, spatially explicit forest data were necessary. In particular, we required and collected data on forest annal increment, forest types, forest roads and main local typologies of forest mechanization. In addition, we collected information in order to estimate the economic value of some ecosystem services, so that we can assess what is the current value and then foresee how this value changes after the withdrawal of forest biomass for energy purposes. Finally, we administrated a questionnaire to some local experts, in order to catch their perception about the impact of exploiting biomass for bioenergy.

DATA ANALYSIS

At this stage, we analysed the data in order to have a picture of the present situation. Thought he collected data, we were able to assess the local energy consumption, the local potentiality for a further development of biomass energy, the expected impact of biomass use for energy, both on the ecosystem services and the local development. The data on the expected impact on ecosystem services are particularly important because they allow the assessment of how the natural capital varies after the withdrawal of biomass from forest. In the Gesso and Vermenagna valleys, we interviewed 8 experts in the fields of renewable energy and nature conservation who estimated the following impacts on the ecosystem services:

- A negative impact on the protection against natural hazards; this impact is reasonable because it is usually thought that cutting trees increments the risk of landslides and superficial erosion. The average impact on the value of protection has been assessed to be around -15%;
- A slightly positive impact on the recreational value of the forests. A positive relationship between recreation and forest biomass withdrawal is justified because, after collecting wood, forest seems to be much more clean and well-kept. The positive impact was estimated to be around 8%.
- A negative impact on the carbon sequestration service. Forests are recognized to be an important carbon pool which helps reduce the negative effects of the greenhouse gases. If biomass is taken out from forest, the future quantity of sequestered carbon will be smaller. Such impact has been assessed to be around -14%.

The cited percentages are used to model the variation of the natural capital stock, after the withdrawal of forest biomass for bioenergy. Once the ecosystem services maps are created, the impact can be seen spatially-explicit, in order to have a clear view of the most affected area.

FORMULATION OF THE ALTERNATIVES

The formulation of the alternative is extremely important, because each alternative has of course different impacts. In particular, in the Gesso and Vermenagna valleys we decided, in compliance with the representatives of the Alpi Marittime Natural Park, to propose 2 scenarios. The first one foresees the exploitation of the public forests, the second one both public and private forests.

GIS MODELLING

r.green.biomassfor calculates the energy potential from biomass sources with a modular structure. Each module calculates the energy potential under different assumptions: theoretical, legal, technical, recommended and economic potentials. The economic potential represents the amount of forest biomass that can be extracted from the forest with an economic convenience, i.e. with a positive cash flow. The analysis of the impact on the ecosystem services is made considering this kind of potential, because it is the one more likely to be extracted. Even though it could be theoretically possible to take more biomass from forest, for example the technical potential instead of the economic one, this is not likely to occur, because it is not economically convenient. The GIS modelling allows the creation of a potential map with the quantity of bioenergy that can be extracted, as you can see in Figure 13 and 14.

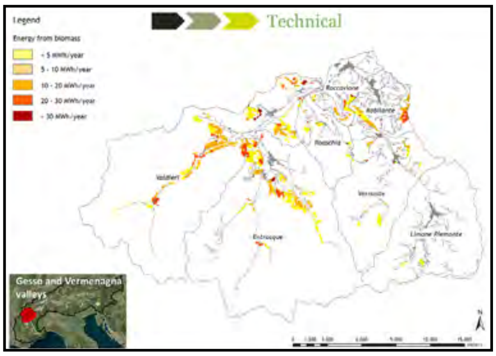


FIGURE 13

Potential of the forest biomass for bioenergy from public forests, exploitable with technical parameters calculated by r.green.biomassfor.technical. The output of the model was provided by the University of Trento that has developed the module r.green.biomassfor.

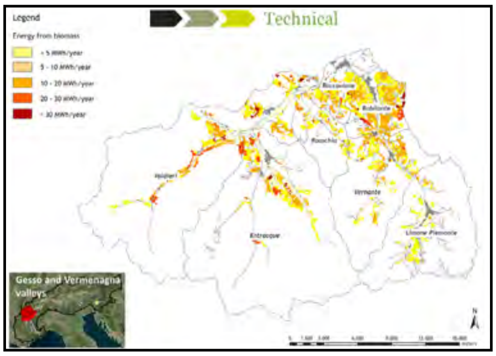


FIGURE 14

Potential of the forest biomass for bioenergy from both private and public forests calculated by r.green.biomassfor.technical. The output of the model was provided by the University of Trento that has developed the module r.green.biomassfor.

The economic potential foresees also a (hypothetical) power plant for biomass, which should be placed into the valley. The location is important because the cost of transport from forest to the plant may change significantly based on its location. Both the scenario foresaw a biomass power plant, nowadays absent, between the two valleys, in order, so that the wood biomass collected could be easily conveyed from the different extraction sites.

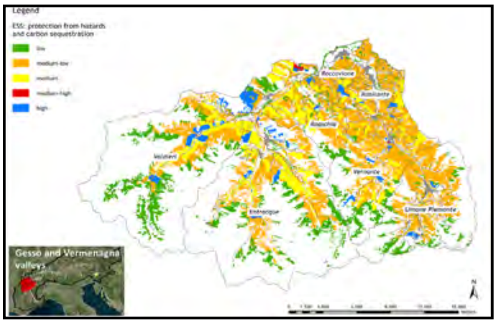


FIGURE 15

The value of ecosystem services before the extraction.

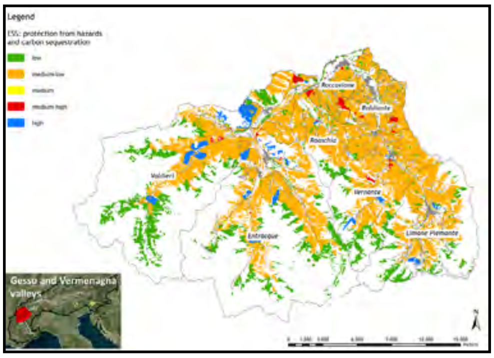


FIGURE 16

Expected value of ecosystem services after the collection of wood biomass for energy.

The power plant siting was made with the aid of a local expert but it was completely hypothetical, no feasibility studies were made and the place was only justified by the efficiency in gathering the collected wood.

The expected impact on the ecosystem services, on the other hand, is represented in figure 15 and 16, showing how the value of the natural capital varies when the wood is extracted. As a general trend, the economic value of ecosystem services is expected to decrease. In particular, the yellow area, indicating a medium level, is enlarged while the orange one is smaller. Other changes are visible in other part of the map. The usefulness of this approach is the spatial dimension of the impacts, in fact with a visible change in the ecosystem services it is possible to make further simulations and scenarios. The high-valuable part of the forest may be kept only for conservation purposes, while less important parts may be exploited further. Of course, the decision should be also made with regard of the local energy supply.

SCENARIO EVALUATION

The spatial visualization of the effects that biomass extraction produces on the environment allows the identification of the less negatively affected area, where biomass for bioenergy can be extracted with less negative consequences and the most affected ones where the extraction is not advisable. An important feature of the SEA is the public participation of the local stakeholders. Each development plan should be shared with the people affected by the decisions, in order to avoid conflicts and facilitate the local acceptance of the projects. In the case of Gesso and Vermenagna valleys case study, results of the potentials and the expected impacts on the environment were presented in three focus groups so that people could choose the preferred development alternative. Participants to the focus groups showed an overall preference towards a further development of the wood-energy chain, but they were skeptical about the settlement of just one power plant. Evidences from the focus groups highlighted people´s belief that local biomass availability is too unpredictable and may change significantly from year to year. In such a situation, a single big (or medium-big) power plant for the 7 municipalities may be too expensive and the return on the investment is too uncertain to justify the construction. Apparently, participants think that more than one power plant; one in each municipality could be

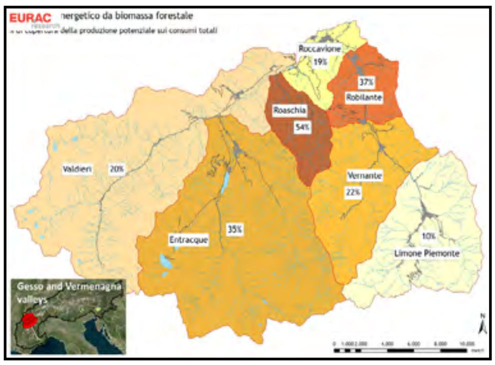


FIGURE 17

Preferred solution for bioenergy development according to the local stakeholders: percentage of energy consumption covered by biomass plant with short chain. The discussion during the focus group was managed by CRA-MPF, Trento.

more beneficial for the local situation (figure 17). Such result was unpredictable for a person living outside the gesso and Vermenagna

valleys and provides a strong evidence that the involvement of the local stakeholders is important during the decision making. The SEA procedure, made with a participatory process, account for such unpredicted results.
Concluding, it is important to highlight that SEA deals not only with environmental impacts, but also with socio-economic aspects of the plans. For this reason, such a procedure could be integrated with other issues, concerning people´s health, future expected incomes and the effects on local developments.

The r.green Decision Support System in Pilot Areas

A DSS tool for policymakers and technicians enables them to take into account renewable energy in the Alps, environmental features and landscapes, and the involvement of local people. This can help them to understand how to optimize biomass, wind, solar, and water energy sustainably (where the use of available resources, such as water and forest biomass, is convenient, and where it would be best to avoid the negative cumulative effects of small power plants or to better manage the use of forest biomass).
To analyze trade-offs and conflicts between energy production and valorization of ecosystem services, the following methodology was applied:

1) Data collection:
- Geographic data, infrastructures, land use, existing power plants…
- Identification of local experts, chosen for their expertise on ecosystem services and/or renewable energy and their knowledge of the local context
- Questionnaire survey to evaluate the potential impacts of renewable energy development on ecosystem services and local actual development

2) Data analysis:
- Definition of current development of renewable energies
- Study of perceived effects of renewable energy development
- Social network analysis of the relationships between local stakeholders
- Total Economic Value maps

3) Formulation of alternatives to the development of renewable energies in the pilot areas
4) Modeling several scenarios of production and ecosystem valorization
5) Scenario evaluation with stakeholders and local community involving:
- Round tables and meetings

Depending on the results of stakeholder involvement, new data can be collected and scenarios developed to define a scenario for the pilot area.

In the recharge.green project, a spatially explicit Decision Support System (DSS) r.green, developed in open source software, identifies and quantifies, based on sustainability and land conservation criteria, the areas suitable for installation of the main renewable energy systems. The software generates maps that can be discussed with the stakeholders and provide a description of different scenarios of renewable energy development.
The modules used for the pilot areas of the recharge.green project are mainly r.green.hydro and r.green.biomassfor, which cover hydropower and biomass, respectively, two of the most relevant renewable sources in the Alps. Several modules were developed for each natural source that allowed consideration of theoretical, technical, and financial variables, and the recommendation of stakeholders. The r.green DSS, already available as a GRASS add-on, can be used through the link command of the GRASS console or by running the standard GUI within Grass. In the next sections, we give a description of the main modules.

WEB

https://grass.osgeo.org/grass70/manuals/addons/r.green.html

WEB

GRASS https://grass.osgeo.org

The forest biomass and r.green.biomassfor

Developed as an add-on of GRASS GIS software, r.green.biomassfor is a holistic model able to quantify in MW/y the potential bioenergy exploitable from wood biomass in forest ecosystems in the light of ecological and economic sustainability. It was developed as an evolution of the UNITN Biomasfor. The model's multi-step approach and internal structure permit the use of a heterogeneous input dataset. To run the model, a series of mandatory variables is required, and the results can be fully refined through the insertion of 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 woodchip price) thus producing different scenarios. The model can produce an estimate of CO_2 emissions and has other multi-functionality parameters, such as fire risk and recreational evaluation.

UNITN BIOMASFOR

See the paper: Sacchelli et al., 2013. Biomasfor - an open-source holistic model for the assessment of sustainable forest bioenergy. iFor. Biogeosci. For. 6, 285-293.

Mandatory data input:

- Forest stand map with yield and increment values.
- Forest management and treatment.
- Ordinary and forest road network.
- Water network.
- Digital elevation model.

Optional data input:

- Soil data (texture, depth, fertility).
- Lakes
- Protected areas.
- Fire risk.
- Costs and marked price of different wood typologies.
- Level of mechanization adopted.

Output data:

- Theoretical maximum bioenergy map exploitable on the basis of forest increment.
- Bioenergy map taking into account the level of mechanization and accessibility of the area.
- Costs and revenues map and data
- CO_2 emissions map and data, and fire risk reduction maps

R.GREEN.BIOMASSFOR.THEORETICAL

This computes the theoretical biomass forestry residual potential, based on the annual/periodic forest increment.
This module permits the maximum bioenergy from forest residual available in a particular area to be evaluated on the basis of annual/periodic forest increment. The mandatory data input is a vector file which has fields with values of increment, management, treatment, and forest surface. The increment value is expressed in cubic meters, the forest surface in hectares, management is an integer value that can be 1 for high forest and 2 for coppice, and the treatment is an integer field that can be 1 for final felling and 2 for thinning. The energy section contains the calorific parameters that permit the biomass to be converted into energy. The output maps are expressed in MWh.

R.GREEN.BIOMASSFOR.LEGAL

This module evaluates the maximum bioenergy from forest residue available in a particular area, on the basis of the prescribed yield. The mandatory data input is a vector file with fields that have values for yield, management, treat-

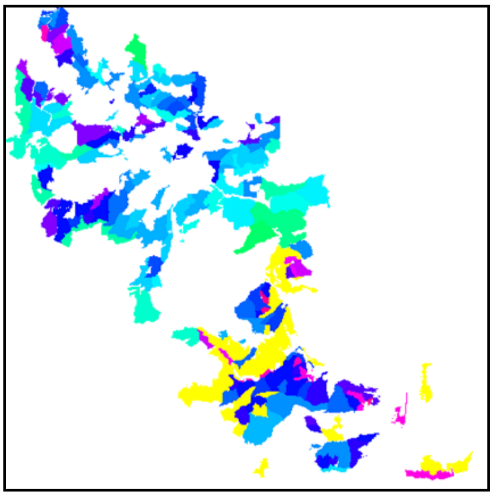


FIGURE 18

The output map is a standardize energy map with the pixel value equal to the corresponding bioenergy estimated.

ment, and forest surface. The yield value is expressed in cubic meters, the forest surface in hectares, management is an integer value that can be 1 for high forest and 2 for coppice, and the treatment is an integer field that can be 1 for final felling and 2 for thinning. The energy section contains the calorific parameters that permit the biomass to be converted into energy. The output maps are expressed in MWh.
A module r.green.biomass.recommended is also available to compute the biomass forestry residual potential considering extra constraints.
This example shows a typical input vector file (Figure 18) with a table composed of fields of increment, forest surface, management, and treatment (Table 2). This example is based on data from the Maè Valley, one of the project's test areas.

```
r.green.biomassfor.legal --over-
write forest=forest@biomas-
for boundaries=Boundary@biomas-
for forest _ column _ yield=yield
forest _ column _ yield _ sur-
face=surface forest _ col-
umn _ management=management for-
est _ column _ treatment=treatment
energy _ tops _ hs=0.49 energy _ cor-
mometric _ vol _ hf=1.97 energy _
tops _ cops=0.55 output _ basename=-
mae
```

R.GREEN.BIOMASSFOR.TECHNICAL

This model computes the biomass forestry residual potential considering the technical constraints of different harvesting techniques.

YIELD	SURFACE	MANAGEMENT	TREATMENT
35.87	800	1	1
16.48	700	1	2
24.82	300	2	1

TABLE 2

Typical input vector example from the Maè Valley.

The hydro-power and r.green.hydro

The model was developed in GRASS GIS software by EURAC (URES group) and is a multi-disciplinary tool that, starting from water availability and elevation data, provides information on hydro potential. Existing plants, different uses of water, mandatory provisions (i.e., the environmental flow, parks, etc…) and technical constraints reduce the number of exploitable rivers. Finally, it is possible to perform an economic analysis using the model. The outputs of the software are maps that depend on the different scenarios used as input.

Mandatory data input:

- Raster file with discharge values along the rivers,
- Raster file with environmental flow,
- Digital terrain model,
- Shape file with existing intakes, reservoirs, and hydro plants (ID, capacity, kind of turbines),
- Areas where hydro plants are forbidden

.

Optional data input:

- Lakes, streets, weirs, electricity grid, parks, area of particular interest,
- Geologic and soil map, cadaster map,
- Duration curves, maximum distance between intake and restitution, minimum distance between restitution and the following intake, increase of environmental flow.

Output data:

- Theoretical and technical potential along rivers,
- Different shape files of potential depending on recommendations (i.e. exclusion of some areas, different lengths of the

pipes, increase of environmental flow, etc…),
- Estimation of the cost of new plants

In the following sections, an explanation of the main modules is reported.

R.GREEN.HYDRO.OPTIMAL

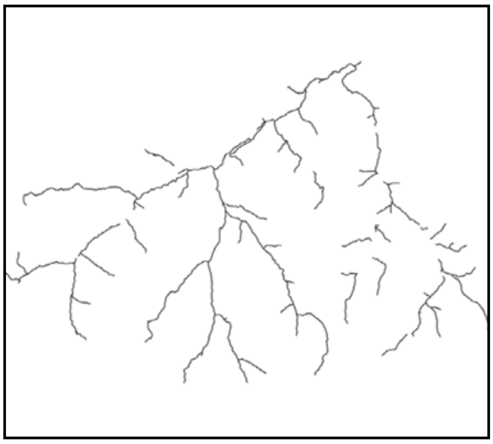
This detects the position of the potential hydropower plants that can produce the highest possible power. The module decides the plant length range and the distance between plants, returning two vector maps showing the segments of rivers exploited by the potential plants and also the intakes and restitution of those plants. The module computes the potential plants in order to maximize the power that can be produced.
The three input files are the rivers considered (vector), the discharge for each point of this river (raster) and the elevation raster map to calculate the gross head. The module maximizes the power over a given range by a brute-force search in order to examine all possible discharge and gross head arrangements. For each potential segment, the potential power is given in kW.

Example

This example is based on the pilot area of Gesso and Vermenagna valleys in the Natural Park of the Maritime Alps, Piedmont, Italy.

FIGURE 19

Input vector map availablestreams.

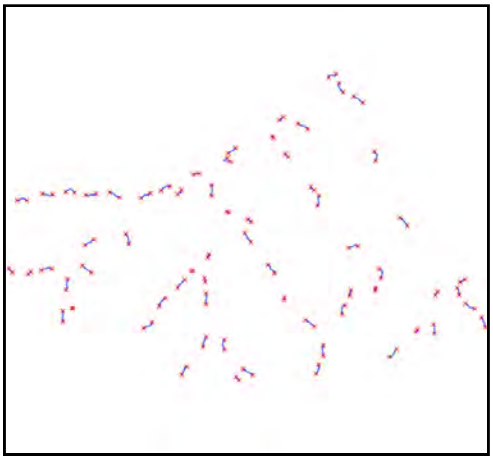


Here is the vector file availablestreams of the streams of interest in which we wish to compute the potential hydropower plants (Figure 19). The river segments already exploited by an existing plant do not appear in the file.
The following command computes the potential plants for a plant length range from 10 to 800 m and a distance between plants of 800 m:

```
r.green.hydro.optimal discharge=-
discharge river=availablestreams
elevation=elevation len_plant=800
distance=800 output_plant=poten-
tialsegments output_point=poten-
tialpoints
d.vect map= potentialpoints
color=red
d.vect map= potentialplants
color=blue
```

FIGURE 20

Output vector maps potential plants (in blue) and potential points (in red).



The output vector maps are shown in Figure 20 which gathers the potential segments vector map (potentialplants, in blue) and the potential intakes and restitution vector map (potentialpoints, in red)

R.GREEN.HYDRO.RECOMMENDED

This detects the position of the potential hydropower plants taking into account the legal constraints and user recommendations. The module is used to decide the plant length range, the distance between plants, the legal discharge that can be exploited, and the areas we wish to exclude from the calculation (e.g., protected areas and those corresponding to user recommendations), and returns a vector file showing the potential plants.
The difference between this module and r.green.hydro.optimal is that here we can con-

sider a legal discharge and add areas that will be deleted from the considered streams map used to compute the potential plants.

The input files are:
A) **The rivers considered (vector)** on which the potential plants will be computed
B) **The current discharge (raster)** for each point of these rivers.

In the section Legal discharge, the Minimal Flow Discharge (MFD) can be taken into consideration. This is the amount of water that has to remain in the river to preserve the ecosystems. There are three different ways to proceed depending on the data available.

1) **The MFD can be considered as a percentage of the natural discharge,** which is the discharge of the river without the structures exploiting the water being taken into account. In this case, the percentage to be considered and the raster map of the natural discharge need to be input. The discharge considered in the calculation will be the current discharge minus the MFD thus calculated.
2) **The raster map with the MFD is already available.** In this case, the discharge considered in the calculation will be the current discharge minus the MFD read in the input raster map. The module r.green.hydro.discharge can compute the raster map of the MFD according to the legislation of some regions.
3) **The raster map with the legal discharge is already available**. In this case, this map can be added as current discharge input and the parameters MFD and natural discharge will not be used.

For each case the raster map of the current discharge is a required input.

C) **The areas to exclude (vector).** Some areas can be excluded by inputting a vector map of the areas with or without a buffer around them. Only the rivers outside these excluded areas will be considered to compute the potential plants. There is also the possibility of adding an input vector map with points of interest. An area corresponding to the fields of vision from these points will then be computed, with the latter corresponding to visibility zones. These areas, or the areas where several visibility zones are superimposed, can be excluded. The number of points for the visibility zones corresponds to the number of visibility zones that are superimposed. For example, if there are three, the areas where two or fewer visibility zones are superimposed will be excluded.
D) **The elevation raster map,** to calculate the gross head
E) **The plant length range**, distance between plants, minimum power and efficiency (optional parameters)

Example

This example is based on the case-study of Mis valley in Belluno province, Veneto, Italy.
Here is the vector file *availablestreams* of the considered streams (Figure 21). The river segments already exploited by an existing plant do not appear in the file.
Superimposed are the vector maps (in grey) of the national park we wish to exclude and the points of interest (in green) used to create the visibility zones. These points were placed according to stakeholder recommendations during a focus group in the Veneto region.
Points of interest are placed in the park so two different cases are presented here:

1) The national park and a buffer of 200 m around it are excluded.
2) The visibility zone from points of interest is excluded.

In the first case, the code used is:

```
r.green.hydro.recommended dis-
charge _ current=currentdischarge
discharge _ natural=naturaldis-
```

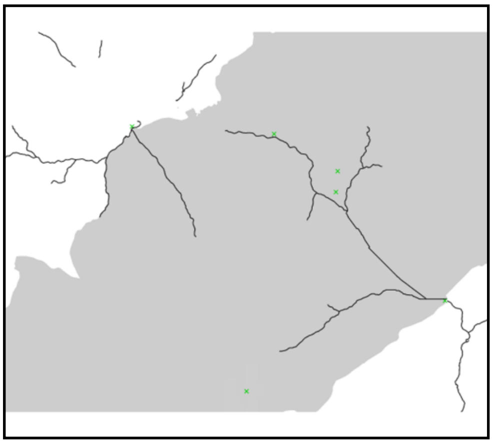


FIGURE 21

Input vector map availablestreams with the national park and points of interest.

```
charge percentage=25.00river=avail-
ablestreams elevation=eleva-
tion efficiency=0.8 len _ plant=400
len _ min=10 distance=150 area=na-
tionalparks buff=200 output _
plant=potentialplants output _
point=potentialpoints
d.vect map= potentialpoints
color=red
d.vect map= potentialplants
color=blue
v.buffer input=nationalparks out-
put=buff _ park distance=200
d.vect map= buff _ park
color=255:179:179 fill _
color=255:179:179 width=1
```

This command calculates the energy potential for plant lengths ranging from 10 to 400 m and a distance between plants of 150 m. The areas with the national park and a buffer of 200 m around it are excluded (Figure 22). The

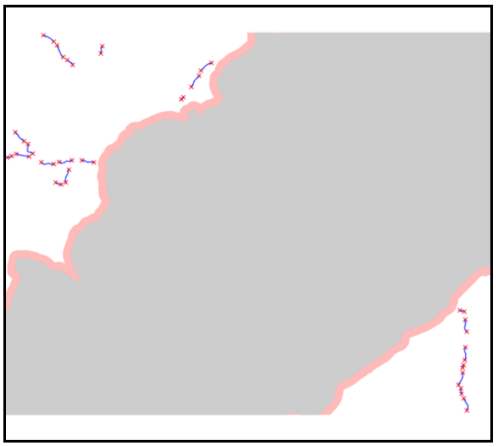


FIGURE 22

Output vector map: superimposition of the potential segments vector file (potentialplants, in blue), the potential restitution vector file (potentialpoints, in red), the excluded national park (in grey) and the buffer (in light red).

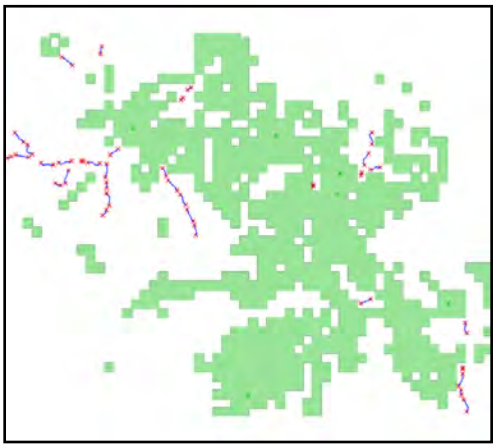


FIGURE 23

Output vector map: superimposition of the potential segments vector file (potentialplants, in blue), the potential intakes and restitution vector file (potentialpoints, in red), the points of interest (in green) and the visibility zones (in light green).

discharge considered here is the current discharge of rivers less than 25% of the natural discharge (the latter corresponds to the MFD). In the second case, the code used is:

```
r.green.hydro.recommended dis-
charge _ current=currentdischarge
mfd=mfd river=availablestreams
elevation=elevation efficien-
cy=0.8 len _ plant=400 len _ min=10
distance=150 points _ view=-
pointsinterest n _ points=1 out-
put _ plant=potentialplants
output _ vis=vis output _ point=po-
tentialpoints
d.vect map= potentialpoints
color=red
d.vect map= potentialplants
color=blue
d.vect map= pointsinterest
color=green
d.vect map= vis color=144:224:144
fill _ color=144:224:144 width=1
```

This command calculates the energy potential for plant lengths ranging from 10 to 400 m and a distance between plants of 150 m. The visibility zones from each point of interest are excluded. The discharge considered here is the current discharge of rivers less the MFD. The MFD was calculated previously and computed in a raster map (Figure 23).

R.GREEN.HYDRO.STRUCTURE

This computes the derivation channel and the penstock for each potential plant and for both sides of the river.

The input maps are the elevation raster map and the map with the segments of potential plants (vector map which can be computed by r.green.hydro.optimal or r.green.hydro.recommended).

The module returns a vector map with the structure for each plant and on both sides of the river. The derivation channel and the penstock are distinguished and reported in the table.

As an option, the module can also compute the vector map with the intake and restitution of each potential plant.

As the current potential especially concerns small hydropower (less than 20 MW), the structure suggested is the structure for small

FIGURE 24

Structure of the plants considered in the module (Micro-hydropower Systems - A Buyer's Guide, Natural Resources Canada, 2004).

hydropower detailed in Figure 24. It is composed of an intake (A) which diverts water from the river. This water is conveyed into a derivation channel (B) with a very low slope and arrives in a forebay tank (C) which regulates the fluctuation of discharge. Finally, the penstock (D) conveys the water with the highest possible head to the turbine-alternator group (E) which produces electricity. The water is then released into the river (restitution F). The following vocabulary is used: the structure of the plant means the part of the plant with the derivation channel, forebay tank, and penstock, whereas the segment of the plant means the

FIGURE 25

Output vector map structplants in black.

part of the river (water not diverted) between intake (A) and restitution (F).
The power is maximized for the highest head in the penstock so that the derivation channel is computed along the same quote (low slope is not mentioned here) as far as the point that maximizes the head along the penstock. The structure is computed for both sides of the river in order to determine which one produces the most power.

Example

This example is based on the case study of Gesso and Vermenagna valleys in the Natural Park of the Maritime Alps, Piedmont, Italy. The following command computes the derivation channel and the penstock for each potential plant and for each side of the river:

```
r.green.hydro.structure elevation=elevation plant=potentialplants output_struct=structplants
```

The result is shown in black in the Figure 25 which brings together the input and output maps.

R.GREEN.HYDRO.FINANCIAL

This module computes the economic costs and values of the plants. It provides a cost-benefit analysis, calculating realization costs and profits for each potential plant to see which ones are feasible. The required input maps are those with the segments of potential plants (vector), the structure of those potential plants (vector), the electric grid (vector), the land use (raster), and the slope (raster).
Each section of the module calculates a cost. The formulas used are valid for all currencies but the values need to be converted. The default values related to a cost are considered in euros.
First, we define the **Total cost**, which is the sum of all the fixed costs corresponding to the construction and implementation of the plant. It includes:

- **Compensation cost:**
This cost represents the sums of money needed to compensate land owners according to current Italian legislation, in cases where plant components are installed according to current Italian legislation.

Input data are:

- Raster map with the land use value [currency/ha];
- Raster map with the taxes [currency/ha];
- Raster map with the value of the topsoil [currency/ha];
- Scalar value with the interest rate (default value: 0.03);

- The life of hydropower plant [year] (default value: 30);
- A scalar with the average width excavation [m] (default value: 2);
- Raster resolution;
- Raster map with the stumpage value [currency/ha];
- Raster map with the rotation period value per land use type [year];
- Raster map with the average age of plant [year];

The user can add directly the maps of taxes, stumpage value, rotation period, and average year. Otherwise, the maps can be computed using the land use raster map and the values reclassified with the GRASS module r.reclass. The program creates the reclassified maps if the user provides the input text files for each category (the input data is the path of the text file). Here is an example of a text file to create the *landvalue* raster map (the costs are in currency/ha):

```
1 = 0 rocks, macerated, glaciers
2 = 0 urbanized areas, infrastructure
3 = 0 shores
4 = 0 waters
5 = 200 gardens
6 = 4000 mining areas
7 = 2000 agricultural areas
8 = 1500 meadows
9 = 1000 areas with predominantly pastoral value
10 = 3000 forestry land
```

Once the calculation is done, a new column with the compensation cost is added to the table of the input map of potential plants. A raster map with the compensation cost can also be computed, as well as a raster map with the value of the topsoil (See Optional section).

– **Excavation cost:**
This cost concerns the excavation works to create channels.

The inputs are:

- Raster map with the slope in [%];
- Raster map with values of minimum excavation costs [currency/mc]
- Raster map with values of maximum excavation costs [currency/mc]
- Width of the excavation [m] (default value: 2);
- Depth of the excavation [m] (default value: 2);
- Length of the excavation [m] which depends on the channel lengths;

If the user does not have the raster maps with the excavation costs, the latter can be computed from the land use raster map if the user provides a text file with the reclassification values (from land use value to excavation cost [min or max]). This is the same principle as that explained above for *landvalue*, taxes, stumpage, rotation period per land use type, and average age of plant. The user can choose to put a slope limit above which the cost will be equal to the maximum cost.
A new column with the excavation cost is then added to the table of the input map with potential plants. A raster map with excavation cost can also be computed (see Optional section).

– **Electro-mechanical cost:**
This is the cost of the electro-mechanical equipment which includes the turbine, alternator, and regulator. It represents a high percentage of a small hydropower plant budget (around 30% and 40% of the total sum). A new column with the electro-mechanical costs is added to the table of the input map with potential plants.

– **Supply and installation cost for pipeline and power line:**
This is the sum of the supply and installation costs for the derivation channel, the penstock (both of which make up the pipeline), and the power line which links the transformer near the turbine to the existing grid.

– **Power station cost:**
This relates to the construction cost of the building housing the power station. It is considered as a percentage of the electro-mechanical cost (default 0.52).

– **Inlet cost:**
This concerns the construction cost of the water intake structure. It is considered as a percentage of the electro-mechanical cost:

The module then calculates the **maintenance cost per year**. The **yearly revenue** corresponds to the revenues from selling all the electricity the plant produces in a year. Finally,

all these values allow the **Net Present Value (NPV)** to be calculated. It is the sum of the present values of incoming and outgoing cash flows over a period of time. It advises whether there are any profits and thus if the plant is feasible.
More concretely, the program computes the following results:

- the input map with the structure of the plants has an updated table with the different costs of construction and implementation and their sum (tot_cost).
- the output map created shows the structure of the potential plants with a reorganized table. The latter does not differentiate between derivation channel and penstock. Each line gives the intake_id, plant_id, side (structures are computed on both sides of the river), power (kW), gross_head (m), discharge (m3/s), tot_cost (total cost for construction and implementation), yearly maintenance cost, yearly revenue, net present value (NPV) and max_NPV. The structure of potential plants is given for each side of the river, max_NPV is 'yes' for the side with the highest NPV and 'no' for the other side.
- the input map with the segments of the plants has an updated table with the total cost, yearly maintenance cost, yearly revenue, and the net present value. The parameter "segment_basename" (in the Input column) allows a prefix to be added to the column names to show the results for different cases in the same table without overwriting the columns.
- In the Optional section, there is the possibility of creating three raster maps showing the compensation, excavation, and topsoil values.

Example

This example is based on the case-study of the Gesso and Vermenagna valleys in the Natural Park of the Maritime Alps, Piedmont, Italy. The input vector file are *techplants* with the structure of the potential plants and the technical value of power (including head losses and efficiencies, computed by r.green.hydro.technical) and the vector map with the segments of river *potentialplants*.
The following command updates the table of structplants and segplants adding the costs:

```
r.green.hydro.financial plant=potentialplants struct=techplants plant_head_column=net_head landuse=landuse rules_landvalue=/pathtothefile/landvalue.rules rules_tributes=pathtothefile/tributes.rules rules_stumpage=/pathtothefile/stumpage.rules rules_rotation=/pathtothefile/rotation.rules rules_age=/pathtothefile/age.rules slope=slope rules_min_exc=/pathtothefile/excmin.rules rules_max_exc=/pathtothefile/excmax.rules electro=grid output_struct=ecoplants compensation=comp excavation=exc upper=upper
```

It also creates four new raster maps (*ecoplants, comp, exc, and upper*):

- *ecoplants* which shows the structure of the potential plants. The table contains these four columns (total cost, maintenance cost, revenue, and NPV) :
- *comp* which shows the compensation values (in currency) for each land use (Figure 26).
- *upper* which shows the values of topsoil (in currency) for each land use.
- *exc* which shows the excavation value (in currency) for each land use.

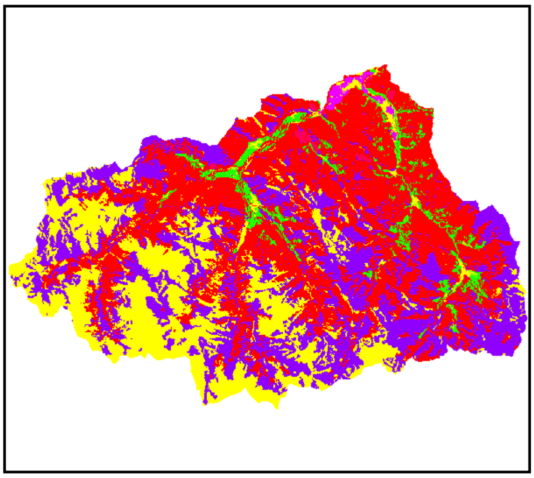


FIGURE 26

Output raster map with compensation values.

Discussion and conclusion

The multi-layer and multi-objective DSS developed under the recharge.green project is designed to help local authorities and other decision makers, technical enterprises and the interested public to develop their own renewable energy strategy. With the help of the online platform “JECAMI,” scenarios and corresponding results from modeling activities at both the alpine and pilot study levels can be visualized and the stakeholder can interact with the system by choosing relevant parameter settings such as the desired technology (choice between bioenergy, wind power, hydropower, solar and a mix of these four renewable energy technologies), the protection level (how much of protected area and what level of protection could still be used for renewable energy production), or the fossil fuel price as a proxy for the subsidies needed to make renewable energy competitive with fossil energy production. On the Alpine level, a lower resolution is chosen, while for the pilot studies, a relatively high resolution is applied. Based on the individual choice of parameters, the DSS calculates the maximum energy production at the lowest costs and the visualization automatically displays the optimal locations for renewable energy production at the desired scale.

Further reading

03

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recharge.green – balancing Alpine energy and nature

The Alps have great potential for the use of renewable energy. Thereby they can make a valuable contribution to mitigating climate change. This, however, means increasing pressures on nature. What could be the impact of such changes on the habitats of animals and plants? How do they affect land use and soil quality? How much renewable energy can reasonably be used? The project recharge.green brought together 16 partners to develop strategies and tools for decision-making on such issues. The analysis and comparison of the costs and benefits of renewable energy, ecosystem services, and potential trade-offs was a key component in this process. The project ran from October 2012 to June 2015 and was co-financed by the European Regional Development Fund in the frame of the European Territorial Cooperation Programme Alpine Space.

This publication gives an overview of the methods of modelling and visualizations of the results produced from the Decision Support Systems at the Alpine and case study levels. Together with other project publications, it can be downloaded from **www.recharge-green.eu**

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