Multi-Criteria Optimal Planning for Energy Policies in CLP*

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Abstract. The number of issues, stakeholders needs and regulations that a policy must consider in the current world is so high that addressing them only with common-sense is unthinkable. Policy makers have to consider disparate issues, as diverse as economic development, environmental aspects, as well as the social acceptance of the policy. A single person cannot be expert in all these subjects. Thus, to obtain a well assessed policy in the current complex world one can adopt decision support systems featuring optimization components.

Leveraging on previous work on Strategic Environmental Assessment, we developed a fully-fledged system that is able to provide optimal plans with respect to a given objective, to perform multi-objective optimization and provide sets of Pareto optimal plans, and to visually compare them. Each plan is environmentally assessed and its environmental footprint is provided in terms of emissions, global warming effect, human toxicity, and acidification. The heart of the system is an application developed in a popular Constraint Logic Programming system on the Reals sort. It has been equipped with a web service module that can be queried through standard interfaces. An intuitive graphic user interface has been added to provide easy access to the web service and the CLP application.

Keywords: CLP applications, Strategic Environmental Assessment, Regional Energy Planning

1 Introduction

Policy making, in the current connected world, has to consider such a number of issues that a single person cannot possibly consider without introducing vast approximations. For example European regions should provide Regional Energy Plans to define strategic objectives and political actions for the energy sector. These policies must take into consideration

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* This paper is an extended version of [1]

- the current energy balance in the region: how much energy is produced/consumed in the region (both electrical and thermal energy can be included) per year, how much is imported/exported;
- forecasts for the future, such as the foreseen energy request or the cost of energy for the following years;
- existing and new directives, one example being the EU 20-20-20 initiative that poses three challenging targets for 2020: 20% improvement of energy efficiency, 20% of the energy should come from renewable sources, and reduction of 20% of greenhouse gas emissions.

The policy contains strategic objectives on the energy share and energy efficiency, measures and activities to cope with the increased energy needs, new regulations, etc. In the case of regional planning, the plan is typically very high-level: it includes activities such as building new power plants for some total output power, the share of each fuel type (nuclear, fossil fuels, biomasses, photovoltaic, windmills, etc.) and the type of produced energy (electric or thermal); but it lacks information about, for example, the actual placement of the plants in the region, or the size of each of the plants. More detailed plans will be done at lower scale, like the province or municipality levels.

By EU directives, regional policies on the energy sector should also include an environmental assessment of the plan. Being the plan so high-level, usually the assessment is done only in a qualitative way.

In a previous work [2], we proposed and compared two alternative logic programming formulations for the strategic environmental assessment of regional plans; one was based on probabilistic logic programming, the other on Constraint Logic Programming (CLP) [3]. We also developed four fuzzy-logic formulations of the assessment problem [4]. All these programs consider a regional plan, given in input, and provide its environmental assessment. An evaluation of the results by an environmental expert suggested that the CLP version provided the most reliable results.

In a following work [5], the CLP program was extended to a first prototype of a regional planner, that generates plans together with their assessment. Although the software was used during the definition of the Regional Energy Plan 2011-2013 of the Emilia-Romagna region [6], the first version had several limitations. First, it had only a command-line interface, and could be used only by an experienced logic programmer (not to mention configuring it). Second, it was able to provide optimal solutions only for one objective function; a serious limitation for a system to be used in the multi-faceted world of policy-making. Third, it was not able to provide any quantitative information on the environmental assessment of the plans. Fourth, it did not consider all the possible actions that a regional plan can implement, but only those actions that amount to creating new infrastructures, plants, or activities, while it was unable to assess the effect of closing power plants or decommissioning obsolete infrastructures.

In this work, we show how the first prototype of the planner was extended to a fully-fledged application. The current version of the software supports

- plans that consider decommissioning obsolete power plants;

- computation of emissions of the power plants for various types of pollutants, in a quantitative way;
- quantitative assessment of the effect of the plan on human health, global warming, and acidification potential;
- multi-criteria optimization considering a variety of objective functions based on qualitative and quantitative information;
- computation of the Pareto front, for two or more objective functions;
- a web interface, that can be accessed both as a Graphical User Interface (GUI) and as a web service.

This work is one of the components of the EU ePolicy project[6]. The final application will use the optimal planner as the center of a large application, that will include an opinion mining component, to assess the acceptance of the policies from the public considering information coming from blogs and social networks; a social simulator component, that will simulate how the population will react to the policies adopted by the Region; a mechanism design component, that will include information from game theory to provide the best allocation schemes of regional subsidies to the stakeholders in the Region; and an integrated visualization component.

The rest of the paper is organized as follows. We first explain the planning and environmental assessment as they are currently done by experts in the Emilia-Romagna region of Italy, and recap the basic CLP program of the first prototype (Section 2). In Section 3, extend it for the new features. We show the design and features of the web service and GUI in Section 4. Finally, we show an experimental evaluation in Section 5, and we conclude in Section 6.

2 Problem considered and CLP solution

The strategic environmental assessment, in the Emilia-Romagna region of Italy, is currently performed by considering two matrices, called *coaxial matrices* [7]. They are a development of the network method [8], and they contain qualitative relations.

The first matrix, $\mathcal{M}$, considers the *activities* that can be undertaken in a plan, and links them with the so-called *environmental pressures*. Environmental pressures can be positive or negative, and they account for the impact on the environment of human activities. Each element m^i_j of the matrix $\mathcal{M}$ can take values {*high*, *medium*, *low*, *null*}, and defines a qualitative dependency between the activity i and the negative or positive pressure j.

The second matrix, $\mathcal{N}$, relates the pressures with the *environmental receptors*, that register the effect of the pressures on the environment. For example, the activity *"coal-fueled power plant"* generates the pressure *"emission of pollutants in the atmosphere"* on the environment; on its turn, this influences the receptor *"air quality"* (as well as other receptors, like *"human wellbeing"* or *"wildlife*

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[6] `http://www.epolicy-project.eu`

wellbeing”). In the same way, the pressure *“emission of greenhouse gases”* influences receptor *“global warming”*; while the pressure *“emission of pollutants in the water”* influences the *“quality of river waters”*. Again, each element n_j^i of the matrix can take the same qualitative values: *high*, *medium*, *low* or *null*.

Currently, the matrices relate 115 activities with 29 negative pressures, 19 positive pressures and 23 receptors. They can be used to assess a variety of regional plans, including Agriculture plans, Forest, Fishing, Energy, Industrial, Transport, Waste, Water, Telecommunications, Tourism, Urban plans. The environmental assessment is usually done using a spreadsheet and eliminating (by hand) those activities that do not belong to the given type of plan; then pressures that are not influenced by remaining activities are removed, and again receptors that are not influenced by the remaining pressures are removed as well. Finally, these reduced matrices are evaluated by environmental experts, that state which parts are most important, mainly considering clusters of *High* values.

Clearly, this process is very slow, experts might overlook combinations of *medium* or *low* values that might produce a significant effect, and, most importantly, it can be done only after the plan has been provided by the policy maker. At this stage, usually only minor modifications can be backpropagated to the plan, and it is practically impossible to compare the effect of the plan with other alternative plans, because this would need to start again another planning phase. As a matter of fact, although the evaluation of alternative plans is obligatory by EU regulations, this is usually not done, because planning and environmental assessment are done in a strictly sequential way.

To overcome the limitations and improve on current practices, we devised an expert system able to automatically assess regional plans [2]; then we extended it to include, in a single software component, a Decision Support System (DSS) able to provide optimal plans together with their environmental assessment [5], in particular for regional energy plans. We now recap the CLP model of such DSS in Section 2.1, and then extend it with new features in Section 3.

2.1 A first CLP solution

We model the planning problem in CLP on the Reals sort (CLP($\mathcal{R}$)). In CLP, one can define a problem through a set of variables, ranging on given domains; the possible assignments are restricted through a set of constraints; a solution is an assignment of values to variables such that all the constraints are satisfied. In many cases, solutions are not all equivalent, but there is an objective function to be maximized or minimized.

Given a number N_a of activities, we consider a vector $\mathbf{A} = (a_1, \dots, a_{N_a})$ in which we associate to each activity a variable a_i that defines its magnitude. The domain of a_i depends on the availability of the resource on the given Region; for example some regions are very windy, while others can exploit better biomasses or solar panels.

We distinguish primary from secondary activities: primary activities are of primary importance for the given type of plan, while secondary activities are those supporting the primary activities by providing the needed infrastructures.

E.g, in an Energy plan, the activities that produce energy (e.g., power plants) are of primary importance; such activities require other activities (e.g., power lines, waste stocking, streets, etc.) to be performed, and they also should be considered in the environmental assessment. Let A^P be the set of indexes of primary activities and A^S that of secondary activities. The dependencies between primary and secondary activities are considered by the constraint:

$$\forall j \in A^S \quad a_j = \sum_{i \in A^P} d_{ij} a_i \tag{1}$$

Each activity a_i has a cost c_i; given a budget B_{Plan} available for a given plan, we have a constraint limiting the overall plan cost:

$$\sum_{i=1}^{N_a} a_i \ c_i \leq B_{Plan} \tag{2}$$

Moreover, given an expected outcome out_{Plan} of the plan, we have a constraint ensuring to reach the outcome:

$$\sum_{i=1}^{N_a} a_i \ out_i \geq out_{Plan}. \tag{3}$$

For example, in an energy plan the outcome can be to have more energy available in the region, so out_{Plan} could be the increased availability of electrical power (e.g., in kilo-TOE, Tonnes of Oil Equivalent). In such a case, out_i will be the production in kTOE for each unit of activity a_i.

Concerning the impacts of the regional plan, an environmental expert suggested to convert the qualitative values in the matrices into the following numeric coefficients: *high*=0.75, *medium*=0.5, *low*=0.25 and *null*=0. We sum up the contributions of all the activities and obtain the estimate of the impact on each environmental pressure:

$$\forall j \in \{1, \ldots, N_p\} \quad p_j = \sum_{i=1}^{N_a} m_j^i \ a_i. \tag{4}$$

In the same way, given the vector of environmental pressures $\mathbf{P} = (p_1, \ldots, p_{N_p})$, one can estimate their influence on the environmental receptor r_i by means of the matrix $\mathcal{N}$, that relates pressures with receptors:

$$\forall j \in \{1, \ldots, N_r\} \quad r_j = \sum_{i=1}^{N_p} n_j^i p_i. \tag{5}$$

Possible objective functions include maximizing the produced energy, minimizing the cost, or maximizing one of the receptors (e.g., maximizing the *"air quality"*), or a linear combination of the above.

3 Extended solution

The CLP($\mathcal{R}$) program described in Section 2.1 was practically used in the development of the 2011-13 Regional Energy plan of the Emilia-Romagna region of Italy. The main objective of the plan was to increase significantly the share of renewable energy in the energy mix, to fulfill the 20-20-20 directive. Indeed, during the years from 2011 to 2013, a large number of new renewable power plants was installed in the region, thanks to subsidies, that make them appealing from the market viewpoint. For the next years, technicians in the region foresee that old power plants fueled by fossil fuels will become obsolete, and they will have to be shut down completely, or, possibly, used only when renewable energy is unavailable or in peak hours. They asked us to extend the DSS to allow for possible closing of power plants, which means that some of the activities could have a negative magnitude: the magnitude, in MW, of oil-based power plants could be reduced with respect to the previous years.

First of all, one should notice that negative activities introduce nonlinearities. For example, if building a new power plant i has a cost c_i in Euros per MW, decommissioning it will not give a *profit* of c_i €$/MW$.

Our implementation is based on the ECL^{i}PS^e CLP language [9,10], using the `eplex` library [11]. The `eplex` library uses very fast solvers based on linear programming or mixed-integer linear programming algorithms; this means that one can impose linear constraints on variables ranging either on continuous domains, or on integer domains. It is well known that linear programming is polynomially solvable, while (mixed) integer linear programming is NP-hard; thus the efficiency of the solution depends on whether there are integer variables or not. To address the non-linearity, we introduced, for each activity a_i that has negative values in its domain, an integer variable $IsPos_i$ and a real variable Pos_i; we wish to obtain that

$$IsPos_i = \begin{cases} 1 \text{ if } a_i \geq 0 \\ 0 \text{ if } a_i < 0 \end{cases} \quad Pos_i = \begin{cases} a_i \text{ if } a_i \geq 0 \\ 0 \text{ if } a_i < 0 \end{cases};$$

this can be obtained by imposing the following linear constraints:

$$\begin{array}{l} Pos_i \geq a_i \\ Pos_i \geq 0 \\ Pos_i \leq a_i + (1 - IsPos_i) \cdot M \\ Pos_i \leq IsPos_i \cdot M \end{array}$$

(where M is a sufficiently large positive number), and with the further integrality constraint $IsPos_i \in \{0, 1\}$. The cost constraint (2) is now rewritten as

$$\sum_{i=1}^{N_a} Pos_i \ c_i \leq B_{Plan}. \tag{6}$$

Similarly, we do not want that secondary activities are decommissioned automatically when decommissioning primary activities; so we impose their relationship only with the positive part of primary activities.

Concerning the environmental assessment, as a first attempt we left the original linear constraints of equations (4-5), but the results were not considered satisfactory by the environmental expert. In fact, a new activity has a number of impacts, some for the construction of the activity (e.g., land use for building a coal power plant, pollution due to the construction site, etc.), and others due to running the activity (e.g., air pollution for burning fuel, water for cooling the plant, etc.). If we assume that the same coefficients in equation (4) can be used also for negative activities, we would correctly account for the second type of impacts, but we would wrongly assume that decommissioning a power plant means restoring the construction site as it was before. Moreover, we would not consider the end-life of the power plants, which can be significant (for example, consider nuclear power plants).

To account correctly for these cases, the environmental expert added new activities on the co-axial matrices (e.g., *"Reduced use of fossil fueled power plants"*), together with their impacts on environmental pressures. All the pressures are now computed only on positive activities, i.e., Equation (4) is substituted with

$$\forall j \in \{1, \ldots, N_p\} \quad p_j = \sum_{i=1}^{N_a} m_j^i \; Pos_i. \tag{7}$$

Then, we considered the new activities as a new type of secondary activities: the *"Reduced use of fossil fueled power plants"* is a secondary activity that becomes positive only when one of the activities *"Coal-based power plant"*, *"oil-based power plant"*, etc., has a negative value. More precisely, we have secondary activities that are linked to the *decommissioning* of other activities: e.g., activity *"Reduction of fossil fuel power plants"* is a secondary activity that is positive if one of the fossil fueled power plants has a negative value. Associated to activities we now have two matrices of dependencies between activities. In particular we have a $N_a \times N_a$ square matrix $\mathcal{D}^+$ where each element d_{ij}^+ represents the magnitude of activity j per unit of activity i, and another $N_a \times N_a$ square matrix $\mathcal{D}^-$ where each element d_{ij}^- represents the magnitude of activity j per unit of reduction of activity i.

The dependency primary-secondary activities in Equation (1) is now substituted with

$$\forall j \in A^S \quad a_j = \sum_{i \in A^P} K_{ij} \tag{8}$$

where

$$K_{ij} = \begin{cases} d_{ij}^+ \cdot a_i & \text{if } a_i \geq 0 \\ d_{ij}^- \cdot (-a_i) & \text{if } a_i < 0 \end{cases} .$$

3.1 Computing emissions

The base CLP program in Section 2.1 was able to provide the environmental assessment only in terms of qualitative information. We extended it to consider also quantitative information, in particular the emission of pollutants in the air for each power plant type. We rely on the data provided by two databases: INEMAR [12] and ISPRA [13]. Both databases provide the various types of pollutants emitted per energy unit (in GJ) in input to the power plant. The considered types of pollutants include Sulfur Oxides (SO_X), Nitrogen Oxides (NO_X), methane, CO, CO_2, N_2O, ammonia, Hexachlorobenzene (HCB), various metals (Arsenic, Cadmium, Chromium, Copper, Mercury, Nickel, lead, Selenium, Zinc), particulate matter (PM10), Dioxins, and some families of compounds, like Polycyclic Aromatic Hydrocarbon compounds (PAH), Polychlorinated biphenyls (PCB), and Non-Methane Volatile Organic Compounds (NMVOC).

While ISPRA provides the average emission for each type of plant (biomasses, oil, coal, etc.), INEMAR provides fine grained information, in which emissions depend also on the type of boiler and the size of the plant (in MW).

We relate the power produced by plants with that of each boiler type. Let N_B the number of boiler types, we have a vector of constrained variables $\mathbf{B} = (b_1, \dots, b_{N_B})$ where b_i is the total output power of the plants using boiler type i. Let $\mathcal{O}$ be the matrix that relates power plants and the different kinds of boiler: each element o^i_j of the matrix is set to 1 if the boiler $b_j \in \mathbf{B}$ can be used for the power plant $a_i \in \mathbf{A}$, and zero otherwise. We impose that the output power of each plant type is the sum of the power of its boilers:

$$\forall i \in \{1, \dots, N_a\} \quad a_i = \sum_{j \in N_B} o^i_j b_j \tag{9}$$

Let $\mathbf{E} = (e_1, \dots, e_{N_e})$ be the vector of emissions and $\mathcal{T}$ the matrix that relates them with the boilers. An element t^i_j of the matrix represents the grams of pollutant $e_i \in \mathbf{E}$ emitted when 1GJ of fuel is provided to the boiler $b_j \in \mathbf{B}$. To calculate the emissions, we have to compute the input energy for each boiler type j, provided the output power b_j:

$$\forall i \in \{1, \dots, N_e\} \quad e_i = \sum_{j \in N_B} t^i_j \left(\frac{T^U}{\eta} b_j \right). \tag{10}$$

T^U is the average running time of a power plant per year (necessary to convert energy into power, and estimated in 8000 hours by our environmental expert) and η is the average efficiency (output power/input power) of power plants, which is prescribed by law as 39% [14].

3.2 Indicators

With the computation of emissions (Section 3.1), the DSS provides new quantitative information, and lets the user find plans that are optimal with respect to objective functions that include emissions; for example, the user might require the plan that minimizes the emission of NO_X or that of CO_2, or even a weighted sum of the two. However, although useful, these might be too fine-grained for the environmental expert, not to mention for a policy maker: indeed, a policy maker could know that NO_X are toxic for humans, but how does that compare with the emission of heavy metal compounds? Instead, the policy maker knows that CO_2 is not harmful for human health, but it is responsible for the greenhouse effect; are there other emissions that worsen global warming?

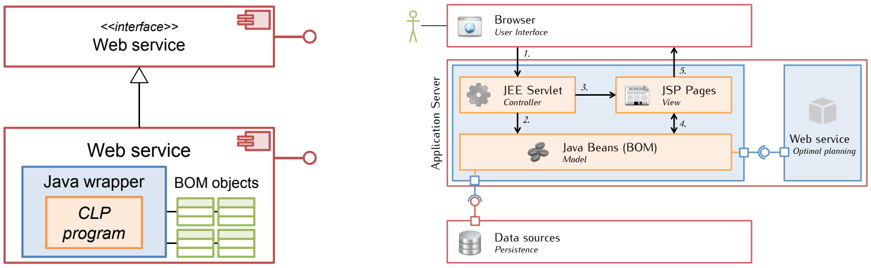
The European Commission [15] published a set of indicators quantifying the effect of various substances on *human toxicity*, *global warming* and *acidification*. For example, Annex 1 of [15] contains 100 chemical substances together with their human toxicity factor, defined as the toxicity of the substance compared to that of lead (Pb). The following annexes contain global warming potentials, relative to CO_2, and acidification potentials, relative to SO_2. By using the weights in the tables, one can provide, e.g., the effect of the plan in terms of human toxicity (in kg of *equivalent emitted lead*), global warming (in kg of *equivalent* CO_2) and acidification (in kg of equivalent SO_2). Moreover, a policy maker may want to optimize on these indicators, and find the plan that minimizes human toxicity, or the greenhouse effect, or any weighted sum of the two.

However, the tables provided by the EC do not always have the same granularity of the information available for emissions. For example, for each plant type we know the emissions of NO_X; unluckily, in [15] we do not have an aggregated value for the toxicity of all the nitrogen oxides, but we have the single toxicity values of NO and NO_2, and they are quite different (respectively, 95 and 300 times that of lead). Even more complicated is for PAH, which include many compounds, e.g., Benzo-a-pyrene (toxicity 0.05 times that of Pb) and Naphthalene (500 times Pb). Our environmental expert suggested that we provided as output, for each indicator, three cases: best, worst, and average, considering respectively the highest toxicity in the compound class, the lowest and an average. Instead, when one of the indicators is in the objective function (e.g., one wants to find the plan with minimum human toxicity), we should optimize the worst case to be more conservative.

3.3 Computing the Pareto front

In the case of regional planning it is very hard (if not impossible) to devise a unique function that includes all the objectives that are important for the user. The optimization component described in Section 2 can provide optimal solutions with respect to one objective function that can be either the total amount of energy produced (both electrical and thermal), or the total cost, or the values of receptors, emissions and indexes explained in the previous sections. We decided to extend it to support also multi-objective optimization, to let the user compute more than one solution, and compare them.

In a multi-objective optimization problem, a Pareto optimal solution is such that it is not possible to improve the result for one objective function, without worsening at least one other objective function. More precisely, in a multi-objective problem with n functions to minimize, a solution μ^* is *Pareto-optimal* if there does not exist another solution μ such that $\mu_j \leq \mu_j^*$ for $1 \leq j \leq n$ and there exists at least one i, $1 \leq i \leq n$ such that $\mu_i < \mu_i^*$. The set of Pareto points is distributed on the so-called Pareto frontier.



(a) The Web service.

(b) The Web application.

Fig. 1: (a) Software stack to deploy the CLP program as a Web service and (b) the typical MVC pattern to exploit it as a Web application.

We implemented the *normalized normal constraint method* [16], an algorithm that works with any type of constraints (linear and nonlinear) and variables (continuous and discrete), and that is able to find an *evenly distributed* set of Pareto solutions. This is an important feature for a DSS, since it supplies the policy maker with a set of solutions that are a good representation of the whole space of Pareto solutions.

4 Graphical User Interface

A software for policy making should be usable by non-IT experts, and have an intuitive GUI able to visualize properly the heterogeneous information inherently present in environmental policies. We deployed the CLP planner as a stateless Web service and access it by means of a stateful Web application. This choice is also convenient from the perspective of a possible composition with the other services of the ePolicy application.

The CLP program is embedded inside a Java wrapper (Fig. 1a) that encodes the requests in CLP terms and decodes the results. This component provides a plethora of Java classes that represent the Business Object Model (BOM) of this domain. Any query addressed to this component and all the returned results are expressed in terms of these objects. Then we use the Apache CXF framework to define a Web Service's Service Endpoint Interface (WS SEI) – an interface containing the signature of the method to call the service – and later to implement such a service taking advantage of the wrapper.

The Web application that stands as a GUI for the Web service is a standard Java servlet (Fig. 1b) following the Model-View-Controller (MVC) pattern: any *request* made through a browser is intercepted by the servlet which acts as a *controller*. The requests are forwarded to the BOM objects inside the *model*; these objects interact with our Web service and persistence layer to produce results. The controller then uses the JavaServer Pages (JSPs) to generate the *view* that becomes the *response* to display in the user's browser. Both the Web service and the Web application are finally deployed to an application server. The

Web application can be accessed at: `http://globalopt.epolicy-project.eu/Pareto/`.

After a welcome page that introduces the software, there are an input page, and a results page. In input, the user can select the language to use (currently, Italian or English), insert bounds (minimum and maximum bounds for each energy source), constraints, and objective functions for the Pareto optimization, as well as the number of Pareto points (s)he wishes to compare. Constraints and objectives can include linear combinations of cost, produced power, receptors, emissions, or indicators. To simplify the input, the user can load the data for the Regional Energy Plan 2011-2013 of the Emilia-Romagna region for Electricity; in the following section we will show the results for this instance. The user can then compute the Pareto optimal plans, and a set of graphs is presented, as described in the next section.

4.1 Interpreting the Results

The results page consists of two *master-slave* panels. The left side-panel is the master and by clicking on any of its entries in one of its three sections, the view in the main panel (the slave) changes accordingly. Each view hosted in the main panel has many tabs and by selecting one of them, an appropriate graph or table is shown.

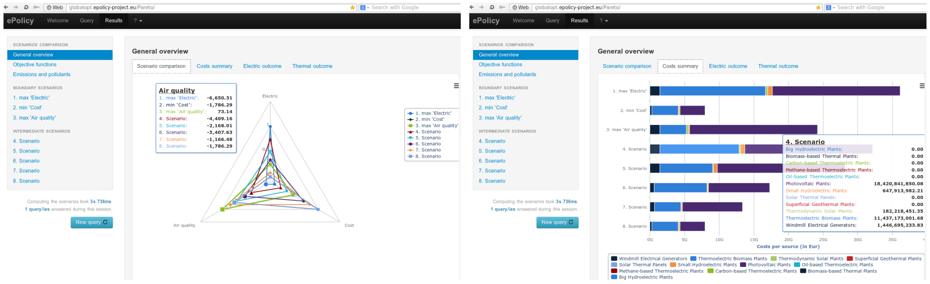
In particular, the left panel let the user select either a *Scenario comparison*, to compare all the generated scenarios, or to get detailed information on one scenario. Scenarios are divided into *boundary scenarios*, that are those that optimize one of the objective functions, and *intermediate scenarios*, that try to balance the various objectives.

Scenarios comparison. By clicking on *General overview* on the left panel, the user can compare the scenarios. One comparison is through a *spiderweb chart* (Fig. 2a) that has an axis for each objective function. Along each axis, the optimal values are far from the origin. Each scenario is represented by a polygon where each vertex is on a different axis. Generally speaking, a bigger polygon implies a better scenario (note that these solutions are Pareto optimal, so one polygon cannot be completely included into another polygon). Hovering the mouse on the axes, one can obtain the values for each plan. To improve legibility, one can deactivate one (or more) plans by clicking on it on the legend.

The scenarios can also be compared through *stacked bar chart*, showing, for each scenario, the distribution of costs per energy source (Fig. 2b), or the amount of electric/thermal energy per source. Again, hovering with the mouse over the graphs, more detailed information is provided.

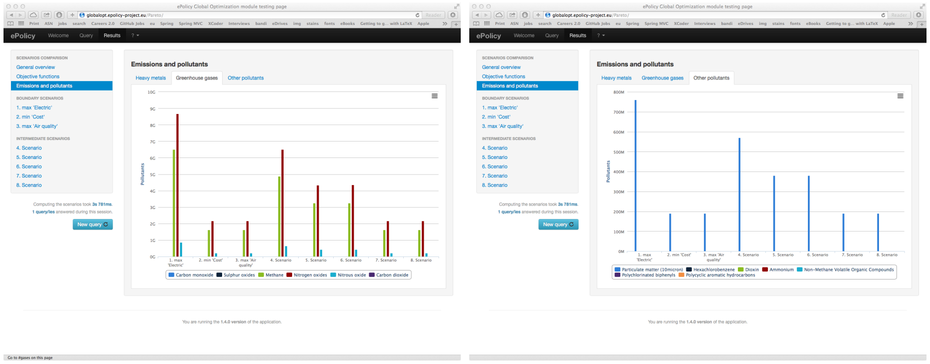
Another scenario comparison is with respect to the values of the *Objective functions* selected by the users.

Finally, by clicking on *Emissions and pollutants*, three tabs (Fig. 3) show, in *basic column charts*, the amount of pollutants divided into the categories *Heavy metals*, *Greenhouse gases,* and *Other pollutants.* With the default data, heavy



(a) Scenario comparison. (b) Costs summary.

Fig. 2: The views associated with the *General overview* entry for *Scenarios comparison.*



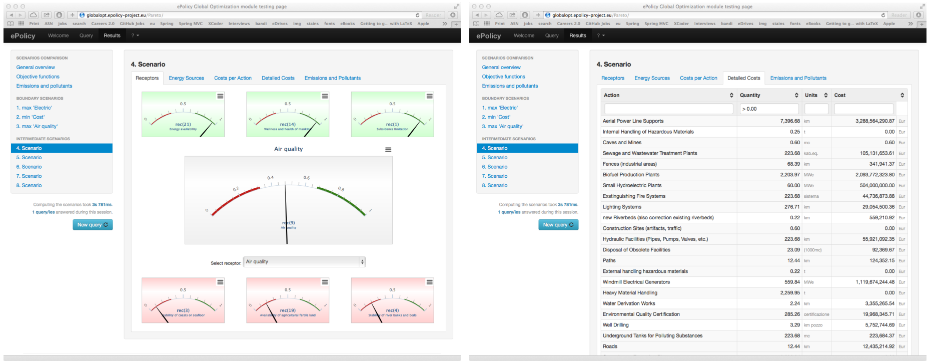
(a) Greenhouse gases. (b) Other pollutants.

Fig. 3: The *Emission and pollutants* views for *Scenarios comparison.*

metals are not present, because in the 2011-2013 plan there are no fossil fuels, the only sources emitting metals.

Boundary and Intermediate scenarios. These sections show detailed information for each of the computed scenarios on the Pareto front. Scenarios are divided into *boundary scenarios*, that are those that optimize one of the objective functions, and *intermediate scenarios*. For each scenario, the following views are available:

- ***Receptors.*** This composite view uses 7 *VU-meter charts* (Fig. 4a). The top part shows the 3 receptors with the best normalised value, while the bottom one the 3 with the worst normalised value. The main chart allows the user to select any receptor and appraise its normalised value. This graph was explicitly requested by an environmental expert to highlight the best and worst receptors.
- There are then four interactive *tabular* views (Fig. 4b) showing respectively, for the chosen scenario, the amount of produced energy per source, the total



Computing the scenarios took 3s 781ms.
1 query/ies answered during this session.

Action	Quantity	Units	Cost	
	> 0.00			
Aerial Power Line Supports	7,396.68	km	3,288,564,290.87	Eur
Internal Handling of Hazardous Materials	0.25	t	0.00	Eur
Caves and Mines	0.60	mc	0.60	Eur
Sewage and Wastewater Treatment Plants	223.68	kab.eq.	105,131,653.61	Eur
Fences (industrial areas)	68.39	km	341,941.37	Eur
Biofuel Production Plants	2,203.97	MWe	2,093,772,323.80	Eur
Small Hydroelectric Plants	60.00	MWe	504,000,000.00	Eur
Exstinguishing Fire Systems	223.68	sistema	44,736,873.88	Eur
Lighting Systems	276.71	km	29,054,500.36	Eur
new Riverbeds (also correction existing riverbeds)	0.22	km	559,210.92	Eur
Construction Sites (artifacts, traffic)	0.60		0.00	Eur
Hydraulic Facilities (Pipes, Pumps, Valves, etc.)	223.68	km	55,921,092.35	Eur
Disposal of Obsolete Facilities	23.09	(1000mc)	92,369.67	Eur
Paths	12.44	km	124,352.15	Eur
External handling hazardous materials	0.22	t	0.00	Eur
Windmill Electrical Generators	559.84	MWe	1,119,674,244.48	Eur
Heavy Material Handling	2,259.95	t	0.00	Eur
Water Derivation Works	2.24	km	3,355,265.54	Eur
Environmental Quality Certification	285.26	certificazione	19,968,345.71	Eur
Well Drilling	3.29	km pozzo	5,752,744.69	Eur
Underground Tanks for Polluting Substances	223.68	mc	223,684.37	Eur
Roads	12.44	km	12,435,214.92	Eur

(a) Receptors.

(b) A tabular view.

Fig. 4: The views associated with each scenario: the *Receptors* chart and the summary tables (*Energy sources*, *Costs per action*, *Detailed costs* and *Emission and pollutants*).

cost for each energy source to be spent in primary and secondary activities, the detailed costs for each activity, and the list of emissions.

5 Experiments

The software computes the optimal solution for one objective in a very short time; on modern computers it is well below 1 second. The multi-objective version has to compute a number of solutions, that depend on the number of scenarios (points on the Pareto front) requested by the user, so the computing time can grow up to some seconds, to compute around 5-10 scenarios (a number of scenarios that can be visualized and compared visually).

In order to assess the scalability, we performed a series of tests by randomly generating a set of data, including the co-axial matrices, the matrix relating primary and secondary activities, the activity costs, etc. In this way, we were able to stress-test the software with instances containing a number of activities, pressures and receptors larger than those in the actual data provided by ARPA.

The experiments were performed on a laptop computer running Linux with a 8x Intel Core i7-3720QM CPU at 2.60GHz; only one core was used in the experiments. The results are plotted in Figure 5, for a single objective. The x-axis is the size of the instance, i.e., the size of the co-axial matrices (each matrix is $N \times N$). The y-axis shows the time required to find the optimal solution.

The computing time, for sizes below 100, is always less than a second. Note that if $N = 100$, the matrix that relates activities and pressures has size $100 \times 100 = 10,000$, while in the real instance it is just $93 \times 48 = 4,464$.

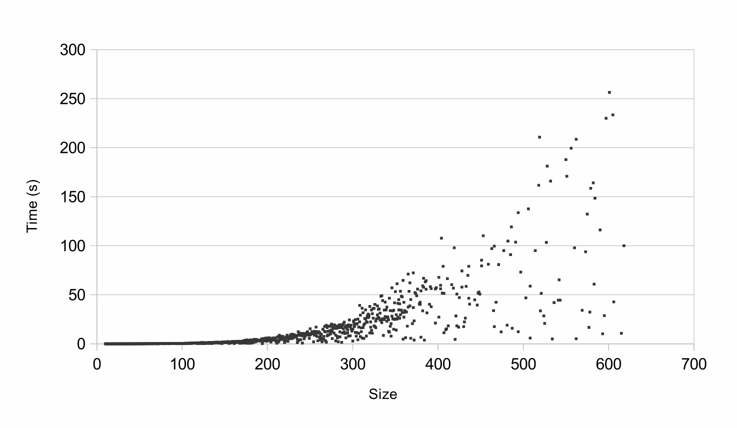


Fig. 5: Run time of randomly generated problems, versus the size N of the problem, assuming the same number N of activities, pressures and receptors.

6 Conclusions and Future Work

We presented a DSS with optimization capabilities based on CLP for the regional planning and with particular emphasis on the environmental aspects of regional policies. The program was practically used to produce the energy plan 2011-2013 of the Emilia-Romagna region in Italy [6], and it is foreseen to use it also for the forthcoming plans. The CLP program is included into a web service, with an intuitive graphical user interface (`http://globalopt.epolicy-project.eu/Pareto/`), and that can be easily integrated with other components. The CLP program will be the heart of the platform of the EU FP7 ePolicy project, that will also include a social simulator, an opinion mining component, and a mechanism design component (based on game theory), all governed by the described CLP program. Preliminary work has been done on the integration of the CLP program with the mechanism design component [17], and a social simulator [18].

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