CHAPTER 12

Constraint and Optimization Techniques for Supporting Policy Making

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CONTENTS

SYMBOL DEFINITIONS

A Vector of activities. For energy sources, it is measured in megawatts (MW).
N_a Number of activities: $N_a = |\mathbf{A}|$.
a_i Element of the **A** vector: $i \in \{1, \ldots, N_a\}$.
P Vector of pressures.

N_p Number of pressures: $N_p = |\mathbf{P}|$.
p_i Element of the **P** vector: $i \in \{1, \ldots, N_p\}$.
R Vector of receptors.
N_r Number of receptors: $N_r = |\mathbf{R}|$.
r_i Element of the **R** vector: $i \in \{1, \ldots, N_r\}$.
O Vector of the outcomes.
o_i Outcome of the activity $\mathbf{A}_i$. For activities that are energy sources, it is the energy (in TOE) produced in 1 year by a plant of 1 MW.
T^o Total outcome of the regional plan. It is the sum of the outcomes of the single activities.
$\mathcal{M}$ Matrix defining the relation between activities and pressures.
m_j^i Element of the matrix $\mathcal{M}$. Dependency of activity a_i on pressure p_j.
$\mathcal{D}$ Matrix defining the dependency between primary and secondary activities.
d_{ij} Element of the matrix $\mathcal{D}$. It measures the dependency of (secondary) activity a_j on (primary) activity a_i.
$\mathcal{N}$ Matrix defining the relation between pressures and receptors.
n_j^i Element of the matrix $\mathcal{N}$. It is the effect of pressure p_i on receptor r_j.
C Vector of costs: $|\mathbf{C}| = N_a$.
c_i Element of the **C** vector. Unit cost of activity a_i.
A^P Set of the indexes of the primary activities; if $i \in A^P$, then $\mathbf{A}_i$ is a primary activity.
A^S Set of indexes of the secondary activities; if $i \in A^S$, then $\mathbf{A}_i$ is a secondary activity.
A^P_{ren} Set of indexes of those primary activities that provide renewable energy.
G Vector of magnitudes.
B Total available budget.
U_i Maximum energy that can be produced by energy source a_i in the Region.
L_i Minimum energy that must be produced by energy source a_i in the Region.
F_i Minimum fraction (percentage) of energy that should be produced by energy source a_i in the Region.

12.1 THE PROBLEM

Public policy issues are extremely complex, occur in rapidly changing environments characterized by uncertainty, and involve conflicts among different interests. Our society is ever-more complex due to globalization, enlargement, and the changing geopolitical situation. This means that political activity and intervention become more widespread, and so the effects of its interventions become more difficult to assess, while at the same time it is becoming ever-more important to ensure that actions are effectively tackling the real challenges that this increasing complexity entails. Thus, those responsible for creating, implementing, and enforcing policies must be able to reach decisions about ill-defined problem situations that are not well understood, have no single correct answer, involve many competing interests, and interact with other policies at multiple levels. It is therefore increasingly important to ensure coherence across these complex issues.

In this chapter we consider, in particular, policy issues related to regional planning, the science of the efficient placement of activities and infrastructures for the sustainable growth of a region. Regional plans are classified into types, such as Agriculture, Forest, Fishing, Energy, Industry, Transport, Waste, Water, Telecommunication, Tourism, Urban Development, and Environment, to name a few. Each plan defines activities that should be carried out during the plan implementation. On the regional plan, the policy maker must take into account impacts on the environment, the economy, and the society. The procedure aimed to assess the impacts of a regional plan is called Strategic Environmental Assessment (SEA) [14] and relates activities defined in the plan to environmental and economic impacts. This assessment procedure is now manually implemented by environmental experts, but it is never applied during the plan/program construction. In addition, this procedure is applied on a given, already instantiated plan. Taking into account impacts *a posteriori* enables only corrective interventions that can, at most, reduce the negative effect of wrong planning decisions.

One important aspect to consider when supporting policy makers with Computational Intelligence approaches is the definition of formal policy models. In the literature, the majority of policy models rely on agent-based simulation [9, 12, 17], where agents represent the parties involved in the decision-making and implementation process. The idea is that agent-based modeling and simulation is suitable for modeling complex systems. In particular, agent-based models permit carrying out computer experiments to support a better understanding of the complexity of economic, environmental, and social systems, structural changes, and endogenous adjustment reactions in response to a policy change.

In addition to agent-based simulation models, which provide "individual-level models," we claim that the policy planning activity needs a global perspective: in the case of regional planning, we need "a regional perspective" that faces the problem at a global level while tightly interacting with the individual-level model. Thus, rather than proposing an alternative approach with respect to simulation, we claim that the two approaches should be properly combined as they represent two different perspectives of the same problem: the individual and the global perspective. This integration is the subject of our current research activity. In this setting, regional planning activities can be cast into complex combinatorial optimization problems. The policy maker must take decisions satisfying a set of constraints while at the same time achieving a set of (possibly conflicting) objectives such as reducing negative impacts and enhancing positive impacts on the environment, the society, and the economy. For this reason, impact assessment should be integrated into the policy model so as to improve the current procedure performed *a posteriori*.

In previous work [7] we experimented with two different technologies to address the Strategic Environmental Assessment of a regional plan, that is, assessing the effects on the environment of a given plan. The technologies we applied were Constraint Logic Programming (CLP) [11] and Causal Probabilistic Logic Programming [18]. Gavanelli et al. [8] proposed a fuzzy model for the SEA. While being far more expressive than a traditional CLP approach, it is less usable within a regional planning decision support system. We evaluated a previous regional plan with the two models, and proposed the outputs to an environmental expert. The expert compared the two outputs and chose the CLP model as closest to a human-made assessment.

In this work we extend the CLP model used for the assessment and apply it to the planning problem—that is, deciding which actions should be taken in a plan. In the model, decision variables represent political decisions (e.g., the magnitude of a given activity in the regional plan), potential outcomes are associated with each decision, constraints limit possible combinations of assignments of decision variables, and objectives (also referred to as criteria) can be used either to evaluate alternative solutions, or be translated into additional constraints. The model has been solved with Constraint Logic Programming [11] techniques, and tested on the Emilia-Romagna regional energy plan. The results have been validated by experts in policy making and impact assessment to evaluate the accuracy of the results.

Further constraint-based approaches have been proposed for narrower problems in the field of energy, such as locating biomass power plants in positions that are economically affordable [2, 5, 6] and environmentally sustainable [4]. Other approaches have been applied to wind turbine placement [10]. The problem faced in this chapter is much broader, as the region should decide which strategic investments to perform in the next 2 to 3 years (with a longer vision to 2020) in the energy field. All specific details are left to the implementation of the plan, but are not considered at the Regional Planning stage. To the best of our knowledge, this is the first time that constraint-based reasoning has been applied to such a wide and strategic perspective.

12.1.1 Regional Planning and Impact Assessment

Regional Planning is the result of the main policy-making activity of European regions. Each region has a budget distributed by the Operational Programme (OP); an OP sets out each region's priorities for delivering the funds. On the basis of these funds, the region has to define its priorities: in the field of energy, one example of priority is increasing the use of renewable energy sources. Then, a region should decide which activities to insert in the plan. Activities may be roughly divided into six types:

1. Infrastructures and plants
2. Buildings and land use transformations
3. Resource extraction
4. Modifications of hydraulic regime
5. Industrial transformations
6. Environmental management

Also, a magnitude for each activity should be decided, describing how much of a given activity is performed.

Each activity has an outcome (such as the amount of energy produced or consumed) and a cost. We have two vectors, $\mathbf{O} = (o_1, \ldots, o_{N_a})$ and $\mathbf{C} = (c_1, \ldots, c_{N_a})$, where each element is associated to a specific activity and represents the outcome and cost per unit of an activity.

There are constraints linking activities: for example, if a regional plan decides to build three biomass power plants (primary activities for an energy plan), each of these plants should be equipped with proper infrastructures (streets, sewage or possibly a small village nearby, power lines), also called *secondary activities*. We thus have a matrix of dependencies between activities. In particular, we have an $N_a \times N_a$ square matrix $\mathcal{D}$ where each element d_{ij} represents the magnitude of activity j per unit of activity i.

Taking as an example the Emilia-Romagna Regional Energy Plan approved in 2007, some objectives of the policy makers are the production of a given amount of energy (400 additional megawatts from renewable energy sources), while reducing the current greenhouse gas emission percentage by 6.5% with respect to 2003. In addition, the budget constraint limiting the amount of money allocated to the energy plan by the Regional Operational Programme was 30.5M€ in 2007.

The policy maker must also take into account impacts on the environment, the economy, and the society, as defined by a Strategic Environmental Assessment that relates activities defined in the plan to environmental and economic impacts. In fact, each activity has impacts on the environment in terms of positive and negative pressures. An example of positive pressure is the increased availability of energy, while an example of a negative pressure is the production of pollutants. Pressures are further linked to environmental receptors such as the quality of the air or of surface water. On both pressures and receptors, there are constraints: for example, the maximum amount of greenhouse gas emissions of the overall plan.

One of the instruments used for assessing a regional plan in Emilia-Romagna are the so-called *coaxial matrices* [3], a development of the network method [16].

One matrix $\mathcal{M}$ defines the dependencies between the above-mentioned activities contained in a plan and *impacts* (also called *pressures*) on the environment. Each element m_j^i of the matrix $\mathcal{M}$ defines a qualitative dependency between the activity i and the impact j. The dependency can be *high, medium, low,* or *null*. Examples of negative impacts are energy, water, and land consumption; variation of water flows; water and air pollution; and so on. Examples of positive impacts are reduction in water/air pollution, reduction in greenhouse gas emission, reduction in noise, natural resources saving, creation of new ecosystems, and so on.

The second matrix $\mathcal{N}$ defines the dependencies between the impacts and environmental receptors. Each element n_j^i of the matrix $\mathcal{N}$ defines a qualitative dependency between the impact *i* and an environmental receptor *j*. Again, the dependency can be *high, medium, low,* or *null*. Examples of environmental receptors are the quality of surface water and groundwater, the quality of landscapes, energy availability, wildlife wellness, and so on.

The matrices currently used in Emilia-Romagna contain 93 activities, 29 negative impacts, 19 positive impacts and 23 receptors, and assess 11 types of plans.

12.2 WHY CONSTRAINT-BASED APPROACHES?

The regional planning activity is now performed by human experts who build a single plan, considering strategic regional objectives that follow national and EU guidelines. After devising the plan, the agency for environmental protection is asked to assess the plan from an environmental point of view. Typically, there is no feedback: the assessment can state that the devised plan is environmentally friendly or not, but it cannot change the plan. In rare cases, it can propose corrective countermeasures, which can only mitigate the negative impact of wrong planning decisions. Moreover, although regulations state that a significant environmental assessment should compare two or more options (different plans), this is rarely done in Europe because the assessment is typically manual and requires a long effort. Even in the few cases in which two options are considered, usually one is the plan and the other is the absence of a plan (i.e., do nothing).

Constraint-based modeling overcomes the limitation of a handmade process for a number of reasons:

- First, it provides a tool that automatically performs planning decisions, considering both the budget allocated to the plan by the Regional Operative Plan as well as national/EU guidelines.
- Second, it takes into consideration environmental aspects during plan construction, thus avoiding trial-and-error schemes.

- Third, constraint reasoning provides a powerful tool in the hand of a policy decision maker as the generation of alternative scenarios is extremely easy and their comparison and evaluation come with no cost. Adjustments can be performed on-the-fly in case the results do not satisfy policy makers or environmental experts. For example, in the field of energy regional planning, by changing the bounds on the amount of energy each source can provide, we can adjust the plan by considering market trends and also the potential receptivity of the region.

12.2.1 A CLP Model

To design a constraint-based model for the regional planning activity, we have to define variables, constraints, and objectives. Variables represent decisions that must be taken. Given a vector of activities $\mathbf{A} = (a_1, \ldots, a_{N_a})$, we associate to each activity a variable G_i that defines its magnitude. The magnitude can be represented either in an absolute way, as the amount of a given activity, or in a relative way, as a percentage with respect to the existing quantity of the same activity. In this chapter we use the absolute representation.

As stated above, we distinguish primary from secondary activities: let A^P be the set of indexes of primary activities and A^S the set of indexes of secondary activities. The distinction is motivated by the fact that some activities are of primary importance in a given plan. Secondary activities are those that support the primary activities by providing the needed infrastructures. The dependencies between primary and secondary activities are considered by the following constraint:

$$\forall j \in A^S \quad G_j = \sum_{i \in A^P} d_{ij} G_i$$

Given a budget B_{Plan} available for a given plan, we have a constraint limiting the overall plan cost as follows:

$$\sum_{i=1}^{N_a} G_i \, c_i \leq B_{Plan} \tag{12.1}$$

Such a constraint can be imposed either on the overall plan or on parts of it. For example, if the budget is partitioned into chapters, we can impose Equation (12.1) on the activities of a given chapter.

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

$$\sum_{i=1}^{N_a} G_i \; o_i \geq o_{Plan}$$

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

Concerning the impacts of the regional plan, we sum up the contributions of all the activities and obtain an estimate of the impact on each environmental pressure:

$$\forall j \in \{1,\ldots,N_p\} \quad p_j = \sum_{i=1}^{N_a} m_j^i \; G_i \tag{12.2}$$

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:

$$\forall j \in \{1,\ldots,N_r\} \quad r_j = \sum_{i=1}^{N_p} n_j^i p_i \tag{12.3}$$

Moreover, we can have constraints on receptors and pressures. For example, "greenhouse gas emission" (that is, a negative pressure) should not exceed a given threshold.

Concerning objectives, there are a number of possibilities suggested by planning experts. From an economic perspective, one can decide to minimize the overall cost of the plan (that is, in any way subject to budget constraints). Clearly, in this case the most economic energy sources are preferred, despite their potentially negative environmental effects (which could be anyway constrained). On the other hand, one could maintain a fixed budget and maximize the produced energy. In this case, the most efficient energy sources will be pushed forward. Or the planner might prefer a *green* plan and optimize environmental receptors. For example, one can maximize, say, the air quality, or the quality of the surface water. In this case, the produced plan decisions are less intuitive and the system we propose is particularly useful. The link between decisions on primary and secondary activities and consequences on the environment are far too complex to be manually considered. Clearly, more complex objectives can be pursued by properly combining the above-mentioned aspects.

12.3 THE REGIONAL ENERGY PLAN

We can now describe how to cast the general model for regional planning described above into the model for designing a regional energy plan. The first step is to identify primary and secondary activities. In the context of a regional energy plan, the environmental and planning experts made the following distinction. Primary activities are those capable of producing energy, namely renewable and nonrenewable power plants. Secondary activities are those that support energy production, such as activities for energy transportations (e.g., power lines) and infrastructures supporting the primary activities (e.g., dams, yards).

One important aspect to account for when designing a regional energy plan is the energy source diversification: this means that the trend to allocate funds should not be directed toward a single energy source, but should cover both renewable and nonrenewable energy sources. This requirement comes from fluctuations of the price and availability of the various resources. For this reason, we have constraints on the minimal fraction F_i of the total energy produced by each source i:

$$\forall i \in A^P \quad G_i o_i \geq F_i T^o$$

where the total outcome T^o is simply obtained as

$$T^o = \sum_{j \in A^P} G_j o_j$$

In addition, each region has its own geophysical characteristics. For instance, some regions are particularly windy, while others are not. Hydroelectric power plants can be built with some careful consideration of environmental impacts, the most obvious being the flooding of vast areas of land. This poses constraints on the maximum energy U_i that can be produced by a given energy source i

$$\forall i \in A^P \ \ G_i o_i \leq U_i$$

Finally, the region priorities should be compliant with European guidelines, such as the 20-20-20 initiative that aims at achieving three ambitious targets by 2020: reducing by 20% greenhouse gas emissions, having a 20% share of the final energy consumption produced by renewable sources, and improving by 20% its energy efficiency. For this reason, we can impose constraints on the minimum amount of energy L_{ren} produced by renewable energy sources whose set of activities is referred to as A^P_{ren}. The constraint that we can impose is

$$\sum_{i \in A^P_{ren}} G_i o_i \geq L_{ren}$$

12.4 THE REGIONAL ENERGY PLAN 2011–2013

The constraint-based model described in previous sections has been used in the planning of the regional energy plan for 2011–2013. The system is implemented in the Constraint Logic Programming language ECL^{i}PS^e [1], and in particular uses its Eplex library [15], which interfaces ECL^{i}PS^e with a (mixed-integer) linear programming solver. The computation time is not an issue in this application, and it was hardly measurable on a modern computer.

The regional energy plan had the objective of paving the way to reach the ambitious goal of the 20-20-20 directive, in particular having 20% of energy in 2020 produced by renewable sources. This amount considers not only electric power, but the entire energy balance in the region, including thermal energy and transports.

Transports can use renewable energy by using renewable fuels, such as biogas (methane produced from the fermentation of vegetable or animal wastes) or oil produced from various types of crops. Currently, we do not consider this issue.

Thermal energy can be used, for example, for home heating; renewable sources in this case are thermal solar panels (that produce hot water for domestic use), geothermal pumps (that are used to heat or to refresh houses), and biomass plants (that produce hot water used to heat neighboring houses during winter).

The considered electric power plants that produce energy from renewable sources are hydroelectric plants, photovoltaic plants, thermodynamic solar plants, wind generators and, again, biomass power plants.

For each energy source, the plan should provide the following:

- The installed power, in megawatts
- The total energy produced in a year, in kTOE
- The total cost, in M€.

The ratio between installed power and total produced energy is mainly influenced by the availability of the source: while a biomass plant can (at least in theory) produce energy 24/7, the sun is available only during the day, and the wind only occasionally. For unreliable sources an average for the whole year is taken.

The cost of the plant, instead, depends mainly on the installed power: a solar plant has an installation cost that depends on the square meters of installed panels, which on their turn can provide some maximum power (peak power).

It is worth noting that the considered cost is the total cost of the plant for the regional system, which is not the same as the cost for the taxpayers of the Emilia-Romagna region. In fact, the region can enforce policies in many ways, convincing private stakeholders to invest in power production. This can be done with financial leverage, or by giving favorable conditions (either economic or other) to investors. Some power sources are economically profitable, so there is no need for the region to give subsidies. For example, currently in Italy, biomass is economically advantageous for investors, so private entities are proposing projects to build biomass plants. On the other hand, biomass also produces pollutants; they are not always sustainable (see [4] for a discussion) so local committees are rather likely to spawn against the construction of new plants. For these reasons, there is a limit on the number of licenses the region gives to private stakeholders for building biomass-based plants.

Technicians in the region estimated (considering current energy requirements, growth trends, foreseen energy savings) the total energy requirements for 2020; out of this, 20% should be provided by renewable sources. They also proposed for this amount a percentage to be provided during the plan 2011 to 2013: about 177 kTOE of electrical energy and 296 kTOE of thermal energy.

Starting from these data, they developed a plan for electrical energy and one for thermal energy.

TABLE 12.1 Environmental Assessment of a Plan Using Only Biomass

Subsidence limitation	25.4475793911422
Embankments stability	−696.277574714292
Stability of coasts or seafloor	−21.4612152513278
Stability of river banks and beds	−267.844653150394
Soil quality	−732.083075332985
Quality of seawater	−343.348156768071
Quality of inland surface waters	−669.53249452972
Groundwater quality	−1242.58982368129
Air quality	−897.397559402556
Quality of climate	−189.576828693382
Wellness of terrestrial vegetation	−1531.95274530939
Wellness of wildlife	−2156.42423356061
Wellness of aquatic plants	−1732.32367634811
Wellness and health of mankind	204.340731338623
Quality of sensitive landscapes	−2175.66773468984
Cultural/historical heritage value	−1547.2098822988
Recreation resources accessibility	−64.6744331658445
Water availability	−1163.25455176302
Availability of agricultural fertile land	−827.660112502349
Lithoid resource availability	287.089994706276
Energy availability	57.450758535756
Availability of productive resources	3204.83984275847
Value of material goods	2469.68141448106

We used the model presented in Section 12.3, considering initially only "extreme" cases, in which only one type of energy source is used.

The application provides the optimal plan, together with its environmental assessment—namely, an evaluation of the environmental receptors used by the Environmental Protection Agency (Table 12.1).

To understand the individual contributions of the various energy forms, we plotted all the plans that use a single type of energy in Figure 12.1, together with the plan developed by the region's experts. On the x-axis, we chose the receptor *Air quality* because it is probably the most sensitive receptor in the Emilia-Romagna region. On the y axis, we plotted the cost of the plan. As explained previously, all plans provide the same energy in kTOE, while they may require different installation power (in megawatts).

First of all, we notice that some of the energy types improve the air quality (positive values on the x-axis), while others worsen it (negative values). Of course, no power plant can improve the air quality by itself (as it cannot remove pollutants from the air). The point is that the plant

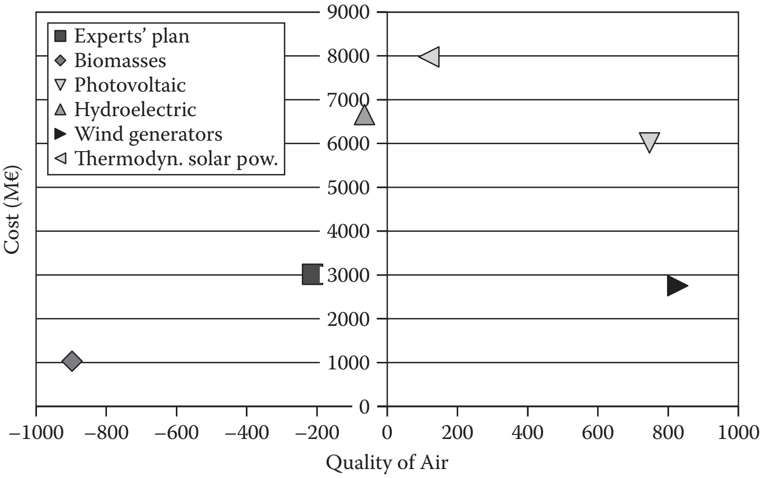

FIGURE 12.1 Plot of the *extreme* plans using only one energy source, compared with the plan by the region's experts.

provides electrical energy without introducing new pollutants; if such energy would not have been provided to the electrical network, it would have been imported from neighboring regions. In such a case, the required energy would be produced with the same mixture of energy sources as in the national production, including those emitting pollutants, so the net contribution is positive for the air quality. Note also that the different energy sources have different impacts on the air quality—not only due to the emissions of the power plants, but also to the impact of the secondary activities required by the various sources.

Finally, note that the "extreme" plans are usually not feasible, in the sense that the constraint on the real availability of the energy source in the region was relaxed. For example, wind turbines provide very good air quality at low cost, but the amount required in the corresponding extreme plan is not possible in the region considering the average availability of wind and of land for installing turbines.

The plan proposed by the region's experts is more *balanced*: it considers the real availability of the energy source in the region and provides a mixture of all the different renewable types of energy. This is very important in particular for renewable sources, which are often discontinuous: wind power is only available when the wind is blowing at a sufficient speed, solar power is only available during sunny days, etc., so having a mixture

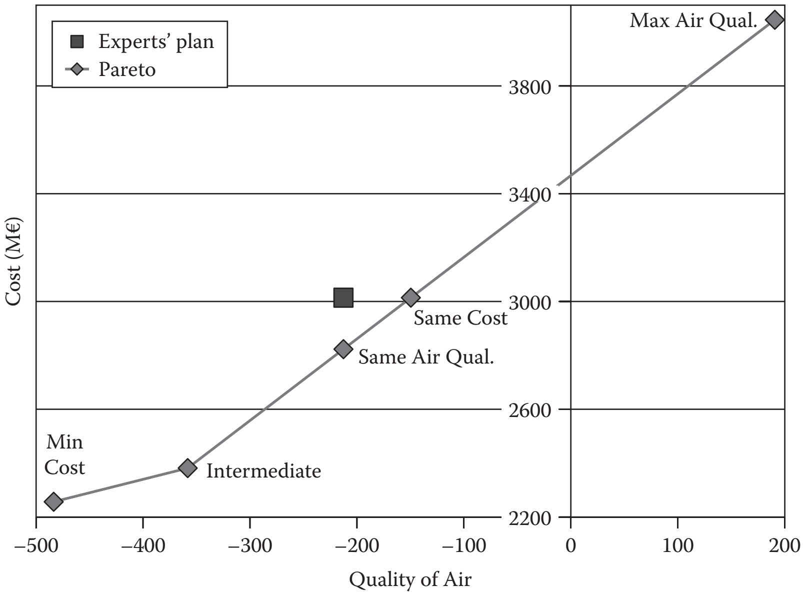

FIGURE 12.2 Pareto frontier of air quality against cost.

of different sources can provide an energy availability more continuous during the day.

In addition to assessing the plan proposed by the experts, we also provided new, alternative plans. In particular, we searched for optimal plans, both with respect to the cost and to the *air quality*. Because we have two objective functions, we plotted the Pareto-optimal frontier: each point of the frontier is a point such that one cannot improve one of the objectives without sacrificing the other. In our case, the air quality cannot be improved without raising the cost; and vice-versa, it is impossible to reduce the cost without sacrificing the air quality. The Pareto frontier is shown in Figure 12.2, together with the experts' plan. The objective function is a weighted sum of single criteria, so our formulation of the problem is linear and we can compute the Pareto frontier by changing coefficients in the weighted sum.

Figure 12.2 shows that although the plan devised by the experts is close to the frontier, it can be improved. In particular, we identified on the frontier two solutions that dominate the experts' plan: one has the same cost but better air quality, while the other has the same air quality but a lower cost.

TABLE 12.2 Energy Plan Developed by the Region's Experts

	Power	Power	Energy	Investments
Electrical	2010	2013	2013	
Power plants	(MW)	(MW)	(kTOE)	(M€)
Hydroelectric	300	310	69.3	84
Photovoltaic	230	850	87.7	2170
Thermodynamic solar	0	10	1	45
Wind generators	20	80	10.3	120
Biomass	430	600	361.2	595
Total	980	1850	529.5	3014

TABLE 12.3 Energy Plan That Dominates the Experts' Plan, Retaining Same Air Quality but with Lower Cost

	Power	Power	Energy	Investments
Electrical	2010	2013	2013	
Power plants	(MW)	(MW)	(kTOE)	(M€)
Hydroelectric	300	303	67.74	25.2
Photovoltaic	230	782.14	80.7	1932.51
Thermodynamic solar	0	5	0.5	22.5
Wind generators	20	140	18.03	240
Biomass	430	602.23	362.54	602.8
Total	980	1832.37	529.5	2823

Table 12.2 contains the plan developed by the region's experts, while Table 12.3 shows the plan on the Pareto curve that has the same air quality as the plan of the experts. The energy produced by wind generators is almost doubled (as they provide a very convenient ratio (air quality)/cost; see Figure 12.1); we have a slight increase in the cheap biomass energy, while the other energy sources reduce accordingly.

Concerning the environmental assessment, we plot in Figure 12.3 the value of the receptors in significant points of the Pareto front. Each bar represents a single environmental receptor for a specific plan on the Pareto frontier of Figure 12.2. In this way it is easy to compare how receptors are impacted by different plans. In the figure, the white bar is associated to the plan on the frontier that has the highest air quality, while bars with dark colors are associated to plans that have a low cost (and, thus, a low quality of the air). Notice that the receptors have different trends: some of them improve as we move in the frontier toward higher air quality (like *climate quality, mankind wellness, value of material goods*), while others

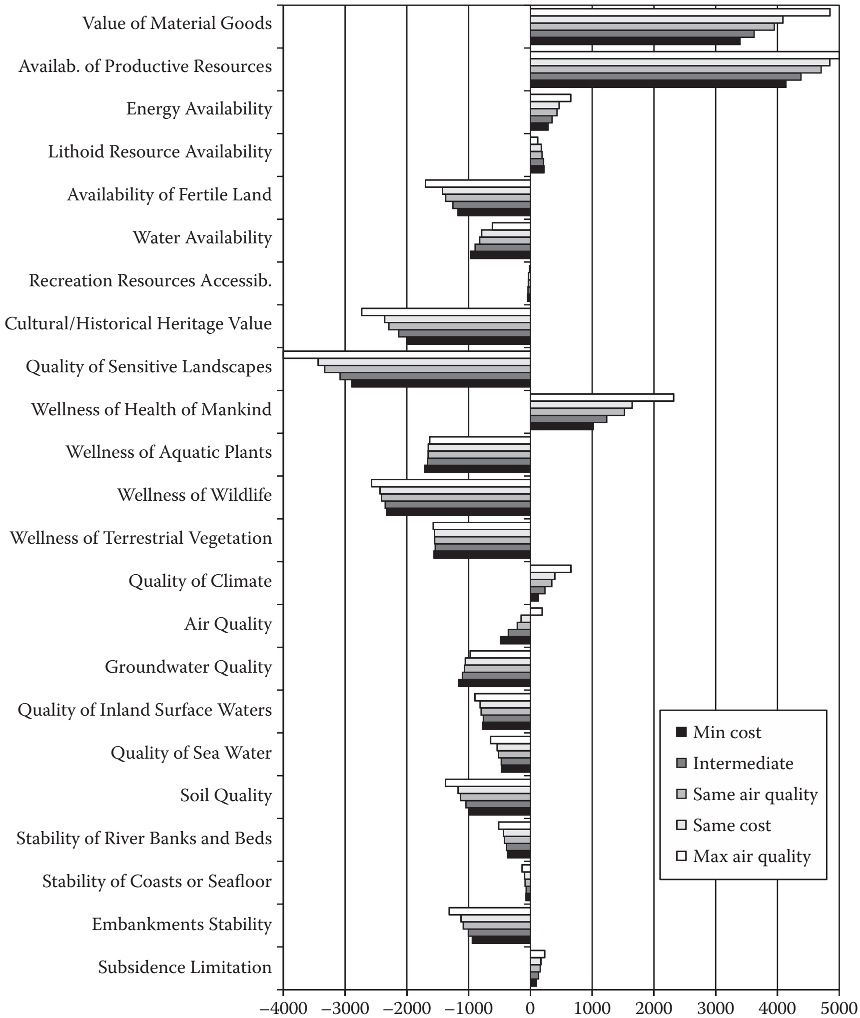

FIGURE 12.3 Value of the receptors on the Pareto front.

improve when moving to less expensive solutions (like *quality of sensitive landscapes, wellness of wildlife, soil quality*). This is due to several reasons, depending both on the type of power plants installed and on the secondary activities.

For example, wind turbines have a good effect on the air quality, but they are also considered aesthetically unpleasant, so they cannot be installed in sensitive zones, such as on hilltops, without having protests from the residents (receptor *quality of sensitive landscapes*). Unluckily, the hills are also the most windy zones in Emilia-Romagna.

Migratory birds follow wind streams to reduce fatigue in their travel over long distances; on the other hand, wind turbines should be installed in windy zones to be effective. So, during migration, birds would have a high likelihood to unexpectedly meet large rotating wind blades, possibly impacting with them; this effect cannot be ignored—in particular for endangered species (receptor *wellness of wildlife*).

12.5 ADDED VALUE OF CLP

The application (including both the assessment and the planning) was developed in a few person-months by a CLP expert. It does not have a graphical user interface yet and is currently usable only by CLP experts; however, it produces spreadsheet files with tables having the same structure as those used for years by the region's experts, so the output is easily understandable by the end user. We are currently developing a Web-based application to let users input the relevant data and try themselves producing plans on-the-fly.

The assessment module [7] was first tested on a previously developed plan and then used during the planning of the 2011–2013 regional energy plan. The various alternatives have been submitted to the regional council, which will have the ability to choose one of them, instead of accepting/rejecting the only proposal, as in previous years.

One of the results is the ability to generate easily alternative plans with their assessment; this is required by the EU regulations, but it is widely disregarded.

Another result is the possibility to provide plans that are optimal; the optimization criteria can include the cost, or one of the various environmental receptors. The user can select two objectives, and in this case the application generates a Pareto front. This helps the experts or the regional council in making choices that are more grounded.

We still do not know which plan the regional council will choose; neither do we know if and how the directives given in the regional plan will be implemented. More refined plans (at the province or municipality level) should follow the guidelines in the regional plan, but it is also possible to introduce modifications during the plan execution. However, in a perfect world in which everything is implemented as expected, the added value of CLP in monetary terms could be the difference of the *investment* columns in the plans in Tables 12.2 and 12.3: 191 M€ saved (by the various actors, public and private, in the whole region) in 3 years.

Finally, the choice of Constraint Programming greatly enables model flexibility. In discussions with experts, it is often the case that they change their minds on some model constraints or on objectives. Therefore, flexibility in dealing with side constraints and in dealing with nonlinear constraints facilitates knowledge acquisition making Constraint Programming the technique of choice for the problem and its future extensions.

12.6 CONCLUSION AND FUTURE OPEN ISSUES

Global public policy making is a complex process that is influenced by many factors. We believe that the use of constraint reasoning techniques could greatly increase the effectiveness of the process by enabling the policy maker to analyze various aspects and to play with parameters so as to obtain alternative solutions along with their environmental assessment. Given the amount of financial, human, and environmental resources that are involved in regional plans, even a small improvement can have a huge effect.

Important features of the system are its efficiency, as a plan is returned in a few milliseconds; and its wide applicability to many regional plans, to provincial and urban plans, and also to private and public projects. The system was used for the environmental assessment of the regional energy plan of the Emilia-Romagna region of Italy. In addition to performing automatically the assessment (that was performed manually in previous years), the assessment for the first time includes the evaluation of alternative plans: this is a requirement of EU regulations that is largely disregarded in practice. Moreover, the alternative plans were produced by optimizing the quality of the environmental receptors, together with the cost for the community of the plan itself.

This work is a first step toward a system that fully supports the decision maker in designing public policies. To achieve this objective, the method must be extended to take into account the individual level, by investigating the effect of a policy over the parties affected by it. This can be achieved by integrating constraint reasoning with simulation models that reproduce the interactions among the parties. In our current research, we are studying how the region can choose the form of incentives and calibrate them in order to push the energy market to invest in the directions foreseen by the Regional Energy Plan [13].

In turn, these models can be enriched by adopting e-Participation tools that allow citizens and stakeholders to voice their concerns regarding policy decisions. To fully leverage e-Participation tools, the system must also be able to extract information from all the available data, including natural language. Thus, opinion mining techniques will be useful in this context.

At the moment, the system can be used only by IT expert people. In order to turn it into a practical tool that is routinely used by decision makers, we must equip it with a user-friendly interface. In particular, we are in the process of developing a Web interface to the constraint solver in order to make it easy to use and widely accessible.

Finally, economic indicators will be used to assess the economic aspect of the plan. Up to now, only budget and a few economic pressures and receptors are considered. We believe that a comprehensive system should fully incorporate this aspect. We will integrate a well-established approach (UN and Eurostat Guidelines) and robust data from official statistics into the system to combine economic accounts (measured in monetary terms) and environmental accounts (measured in physical units) into a single framework useful for the evaluation of the integrated economic, environmental-social performance of regions.

ACKNOWLEDGMENTS

This work was partially supported by EU project ePolicy, FP7-ICT-2011-7, grant agreement 288147. Possible inaccuracies of information are the responsibility of the project team. The text reflects solely the views of its authors. The European Commission is not liable for any use that may be made of the information contained in this chapter.

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