Sustainable Energy Policies: research challenges and opportunities

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Abstract—**Designing sustainable energy policies heavily impacts the economic development, environmental resource management and social acceptance. There are four main steps in the policy making process: planning, environmental assessment, implementation and monitoring. We focus here on the first three steps that are performed ex-ante. We describe in this paper these steps tailored on the energy policy process. We also propose enabling technologies for implementing a decision support system for energy policy making.**

I. Introduction

Policy making is the process by which governments translate their political vision into programmes and actions to deliver outcomes in terms of desired changes in the real world.

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 globalisation, 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. 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.

Policy making in the energy sector accounts the crucial aspect of energy production and energy efficiency that strongly affect economic development, sustainability, and social acceptance. Our energy production is heavily relying on burning fossil fuels, that beside being near exhaustion and coming from politically sensitive regions of the word, produce carbon emissions that are responsible of climate change. Against this background, energy policy making is turning attention toward sustainable energy policies and low carbon economy, by possibly eliminating the direct use of fossil fuels, targeting renewable energy sources, promoting energy efficiency and strategically going toward the smart grid.

An example is the EU 20-20-20 initiative that aims at increasing the energy efficiency of 20%, producing the 20% of energy from renewable energy sources and reducing the 20% of carbon dioxide emissions in 2020. Clearly, this initiative should be perceived at different levels and granularities by member states, regions, provinces and municipalities. This ambitious objective is perceived by devising a set of priorities of intervention defined in the document *Energy 2020 A strategy for competitive, sustainable and secure energy*: achieving an energy efficient Europe, building a truly pan-European integrated energy market, empowering consumers and achieving the highest level of safety and security.

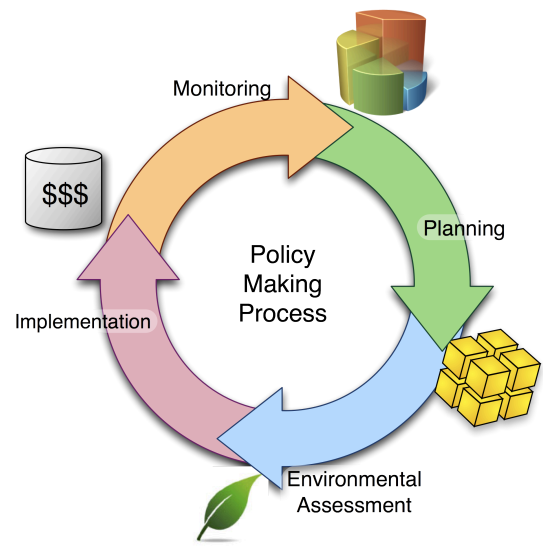

Fig. 1. The policy process phases

Generally speaking, the policy making process traverses four steps, as depicted in figure 1: policy planning, environmental assessment, implementation and monitoring. In the planning step, strategic objectives are set, budget constraints are defined, geo-physical constraints are considered. The assessment phase, that is traditionally performed after the planning step, concerns the evaluation of the impact of the policy plan on the environment, and to a certain extent on economy and society. Implementation consists in defining a set of instruments to support the planning objectives, like incentives, information campaigns, tax exemption and compulsion to name a few. The monitoring step is performed ex-post, to check if the implementation strategies achieve the expected objectives settled during the planning phase.

There are a number of problems in this process at present. First, the planning step and the environmental assessment are performed in sequence: in case a plan contains negative effects on the environment, only corrective countermeasures can be applied a posteriori. If planning and environmental assessment were performed at the same stage, an environmentally well

978-3-9815370-0-0/DATE13/©2013 EDAA

assessed plan could be produced instead. Second, the implementation instruments are decided without any proper strategy nor assessment of their effect on the society. These effects are indeed checked during the monitoring phase to measure if they are conformant with the planning objectives in an ex-post fashion. Third, the steps are always performed manually with no (or very little) ICT support.

Computing techniques are important instruments for aiding governance and policy making: the literature reports attempts to use agent-based simulation [1], opinion mining [2], visual scenario evaluation [3] and optimization [4] to support specific cases of this process, but there is large space for improvement. What is missing is a comprehensive tool that assists the policy maker in all phases of the decision making process. The tool should compute alternative scenarios each comprising both a well assessed regional plan and the corresponding implementation strategies to achieve its objective. Basically, the only step we do not consider in this paper is the monitoring phase which is an ex-post step and is not performed before the policy is indeed implemented.

In this paper, we consider energy policies at regional level and we provide some insights on how to exploit ICT technologies to aid the policy making process.

II. Energy Planning

In many nations, individual regions devise policies for their sustainable growth. This regional planning activity can be targeted at various fields, such as agriculture, forests, fishing, energy, industry, transportation, waste, water, telecommunication, tourism, urban development and environment. The plans define activities that should be carried out to achieve certain development objectives.

In this paper we consider energy plans. A typical objective of a regional energy plan is to increase the share of renewable energy sources in the regional energy balance. This balance does not consider only electric power, but also thermal energy and transports. Transports can use renewable fuels, like biogas or oil produced from crops. Thermal energy can be used e.g. 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), biomass plants, that produce hot water used to heat neighbouring houses during winter. Electric power plants that produce energy from renewable sources are hydroelectric plants, photovoltaic plants, thermodynamic solar plants, wind generators and, again, biomass power plants. We focus here on electric power plants, but similar considerations can be done for thermal energy and transports.

Each region has to forecast the regional energy demand in 2020. To obtain this number the current regional energy balance is considered and extended to 2020. Clearly energy efficiency should play a fundamental role. Thus, actions to foster energy efficiency should be defined in order to reduce the energy demand. In the Italian Emilia Romagna region, the energy demand is computed as depicted in figure 2: the Energy required in 2010 has been derived from the Regional Energy

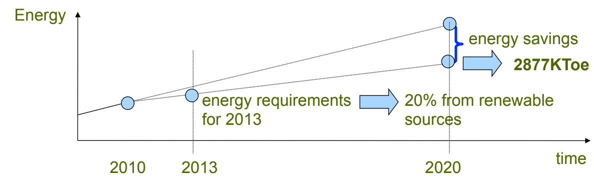

Fig. 2. Energy requirement for the Emilia Romagna region in 2020

Balance. It is projected to 2020. The 20% of the total amount of energy saving through energy efficiency is considered to come up with the expected energy demand.

A region should decide the energy share from renewable sources to achieve the objectives. In the energy plan case, the main actions are energy plants for each specific source in terms of installed power, in MW (Megawatts).

For each energy source, the plan should provide: the installed power, in MW; the total energy produced in a year, in kTOE (TOE stands for Tonne of Oil Equivalent); the total cost, in million euros. The ratio between installed power and total produced energy is mainly influenced by the source availability: 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 on 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). There might be constraints on the budget, on geo-physical characteristics that will be described in the next section.

A. *Technologies for supporting policy planning*

In practice, the regional planning activity can be easily caster into a combinatorial optimization problem. There are a number of technologies supporting decision making and optimization in the energy planning field [5], namely Constraint Programming, Mixed Integer Linear Programming, metaheuristics. They are extremely useful for a number of reasons: first, because they provide a tool that automatically performs planning decisions, taking into consideration the budget allocated on the plan by the Regional Operative Plan, as well as national and EU guidelines. Second, because they can take into consideration environmental aspects during plan construction, avoiding trial-and-error schemes. Third, because they enable the generation of alternative scenarios. Scenario comparison and evaluation comes for free.

We give here an example of a constraint-based model for the energy policy planning. To design a constraint-based model, we have to define variables, constraints and objectives. Variables represent decisions to be taken. We have a vector of activities $\mathbf{A} = (a_1, \ldots, a_{N_a})$. To each activity we associate a decision variable Mag_i that defines the magnitude of the activity itself.

We distinguish primary and secondary activities: some activities are of primary importance in a given plan. Secondary activities are those supporting the primary activities by providing the needed infrastructures. In case of the energy plan, primary activities are those producing energy, namely renewable and non-renewable power plants. Secondary activities are those supporting the energy production, such as activities for energy transportations (e.g., power lines), and infrastructures (e.g., dams, yards).

The first set of constraints takes into account dependencies between primary and secondary activities. Let PA be the set of indexes of primary activities and SA the set of indexes of secondary activities, the dependencies have the form:

$$\forall j \in SA \quad Mag_j = \sum_{i \in PA} d_{ij} * Mag_i$$

A second constraint limits the available budget. Given a budget bud_{Plan} available for a given plan, we have a constraint limiting the overall plan cost as follows

$$\sum_{i=1}^{N_a} Mag_i \ * c_i \leq bud_{Plan}$$

This constraint can be posted either on the overall plan, or on parts of it. For instance suppose we have already partitioned the budget into chapters, we can impose the above constraint only on activities related to a given chapter.

A third constraint concerns the plan outcome. Given an expected outcome out_{Plan} of the plan we have a constraint ensuring to reach it:

$$\sum_{i=1}^{N_a} Mag_i \ * out_i \geq out_{Plan}.$$

In an energy plan the outcome is the produced energy, so out_{Plan} could be the electrical power demand (e.g., in megawatts) minus the one already installed. In such a case, out_i is the production in MW for each unit of activity a_i.

One important aspect to be taken into account when designing a regional energy plan is the energy source diversification: budget allocation should not be directed toward a single energy source, but should be diversified. This requirement comes from fluctuations of the price and resource availability. For this reason, we have posted constraints on the minimal percentage Per_i of the total energy needed to be produced by each energy source i.

$$\forall i \in PA \ \ Mag_i * out_i \geq Per_i * out_{Plan}$$

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

$$\forall i \in PA \ \ Mag_i * out_i \leq Max_i$$

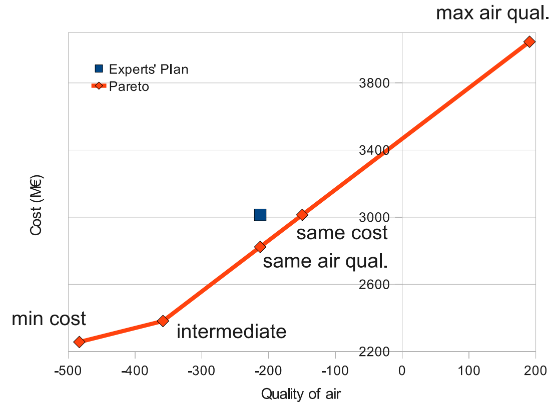

Fig. 3. Pareto Optimal frontier with alternative plan scenarios

Finally, the region priorities should be conformant with European guidelines such as the 20-20-20 initiative aimed at achieving three ambitious targets by 2020: reducing by 20% its 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 Min_{ren} produced by renewable energy sources whose set is referred to as PA_{ren}. The constraint that we can impose is

$$\sum_{i \in PA_{ren}} Mag_i * out_i \geq Min_{ren}$$

Concerning objective functions, there are a number of possibilities as suggested by planning experts. From an economical perspective, one can decide to minimize the overall cost of the plan (that is anyway subject to budget constraints). In this case, the most economic energy sources are considered 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 are taken into account. On the other hand, the planner could decide to produce a *green* plan and consider environmental receptorsmsuch as the air quality, or the quality of the surface water. The produced plan decisions are less intuitive and decision support system is particularly useful. The system partitions the budget on activities to obtain a sustainable plan for a given receptor. Clearly, more complex objectives can be pursued, by properly combining the above mentioned aspects. An example is to use a multi-criteria objective taking into account for example the cost and the air quality. In this case, we come up with a Pareto optimal frontier as depicted in figure 3. Note that the plan provided by expert lies outside the pareto optimal frontier and it is therefore sub-optimal.

III. Strategic Environmental Assessment

The impacts of a policy plan on the environment are evaluated with the so-called Strategic Environmental Assessment (SEA) [6], that relates activities performed in the region to environmental indicators. This assessment procedure is currently performed by environmental experts after a plan has been designed. Taking into account impacts a posteriori enables only corrective interventions that can at most reduce the negative effect of wrong planning decisions.

One of the instruments used for assessing a regional plan in Emilia-Romagna are the so called *coaxial matrices* [7], that are a development of the network method [8]. One matrix $\mathcal{M}$ defines the dependencies betweenthe activities contained in a plan and positive and negative *impacts* (also called *pressures*) on the environment. Each element m^i_j of the matrix $\mathcal{M}$ defines a qualitative dependency between the activity i and the negative or positive 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 of water/air pollution, reduction of greenhouse gas emission, natural resources saving, creation of new ecosystems and so on.

The second matrix $\mathcal{N}$ defines how the impacts influence environmental receptors. Each element n^i_j of the matrix $\mathcal{N}$ defines a qualitative dependency between the negative or positive 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, 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. As far as computational demand is concerned, managing linear constraints is easy (this is clearly an approximation of reality). However, if we consider qualitative aspects and non linear synergies of activities to pressures an of pressures to receptors would greatly complicate the model making its solution computationally challenging.

A. Technologies for Impact Assessment

A number of techniques have been proposed for performing Environmental Assessment of a given plan, namely probabilistic reasoning [9] and fuzzy and multi-valued logic [10]. However, performing the Strategic Environmental Assessment during the plan construction means combining the evaluation and the planning models. This can be easily done in a constraint-based model.

To compute the environmental impact, we sum up the contributions of all the activities and obtain the estimate of the impact on each environmental pressure:

$$\forall j \in \{1, \ldots, N_p\} \quad p_j = \sum_{i=1}^{N_a} m^i_j \; Mag_i. \tag{1}$$

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

$$\forall j \in \{1, \ldots, N_r\} \quad r_j = \sum_{i=1}^{N_p} n^i_j p_i. \tag{2}$$

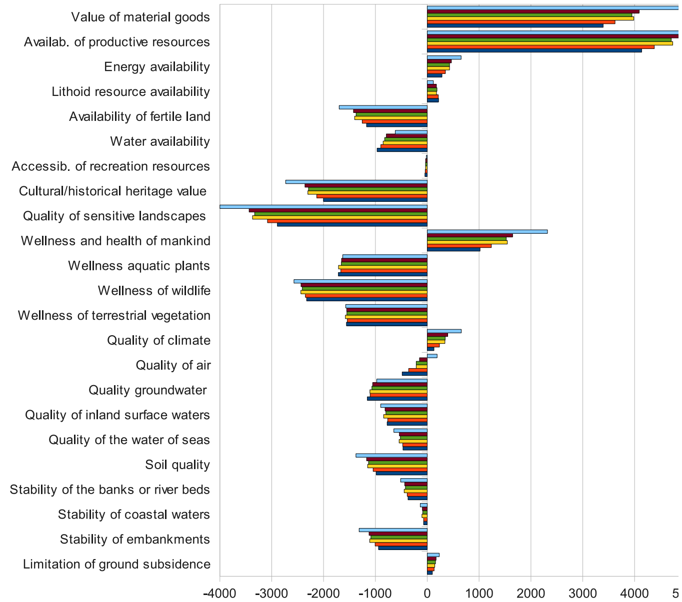

Fig. 4. Receptor comparison on different plan scenarios

We can impose constraints on receptors and pressures. For example, we can say that the greenhouse gas emission (that is a negative pressure) should be constrained by a given threshold.

Merging planning and environmental assessment gives the policy maker to compare different scenarios for what concerns the environmental receptors. For instance, scenarios presented in figure 3 are compared as in figure 4.

IV. Implementation

In general, after a plan is created and assessed, the policy maker should define actions for the plan implementation. Since the region could only devise strategic objectives, but the plants are installed by citizens and enterprises, we have to understand which (set of) policy instruments to implement to achieve the plan objectives. There are a number of instruments to support the energy policy:

- Feed-in tariffs: a fixed and guaranteed price paid to the eligible producers of electricity from renewable sources, for the power they feed into the grid.
- Premium: in a feed-in premium system, a guaranteed premium is paid in addition to the income producers receive for the electricity from renewable sources that is being sold on the electricity market.
- Quota obligations that create a market for the renewable property of electricity. The government creates a demand through imposing an obligation on consumers or suppliers to source a certain percentage of their electricity from renewable sources.
- Investment Grants for renewable generation are often devised to stimulate the take-up of less mature technologies such as photovoltaic.
- Tax exemptions: some countries provide tax incentives related to investments (including income tax deductions or credits for some fraction of the capital investment made

in renewable energy projects, or accelerated depreciation). Other approaches are production tax incentives that provide income tax deduction or credits at a set rate per unit of produced renewable electricity, thereby reducing operational costs.

- Fiscal Incentives: this category includes soft or low-interest loans that are loans with a rate below the market rate of interest. Soft loans may also provide other concessions to borrowers, including longer repayment periods or interest holidays.
- Compulsion: a more radical approach would involve an element of compulsion. For example in at least some urban parts of Scandinavia it is a legal obligation for new constructed homes to be connected to the local heat network.

Beside understanding which policy instruments are available, the region has also to decide how to distribute the available budget, i.e., the mechanism to be adopted. In many regions, for example, incentives are distributed to stakeholders by means of periodical auctions that indeed do not result from a specific strategy, but rather from extemporary actions. In these auctions the bids are ranked on the basis of various criteria (including the co-financing percentage), and the first n bids that satisfy the budget constraint are funded. This mechanism is not necessarily a truthful one. The main problem of a non truthful mechanism is that a bidder is pushed to ask for an incentive for building a photovoltaic plant, even if she would have installed the plant even without a regional contribution.

Therefore, together with the plan, we have to define a proper set of policy instruments, the budget allocated to each of them and a corresponding truthful mechanism to distribute the money. Each solution has a cost and its own impact on the energy market and the society. Understanding the impact of these instruments on the diffusion of renewable energy and its adoption by citizens and enterprises is very complex, but essential for devising the proper instrument portfolio that achieves the plan objectives.

A. Technologies for supporting the Implementation phase

There are mainly two core technologies for supporting the implementation step of the policy making process that can be used either in isolation or as an integrated solution: social simulation and mechanism design.

1) Social simulation: Several modelling techniques, often collectively referred to as social simulation, have successfully been used to represent the responses of societies to policy interventions. Agent Based Modelling (ABM) [11] is the most appropriate to represent complex social dynamics because of its capacity to capture interactions and responses in a spatial environment. However, increasingly methods of social simulation are moving towards a common ground, with agent-based modelling incorporating aspects of system dynamics and microsimulation. An agent-based model is a computational method for simulating the actions and interactions of autonomous decision making entities in a network or system, with the aim of assessing their effects on the system as a whole. Individuals and organisations are represented as agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviours appropriate for the system component they represent for example, producing or consuming. Even a simple agent-based model can exhibit complex behaviour patterns because a series of simple interactions between individuals may lead to the emergence of more complex global scale outcomes that could not have been predicted just by aggregating individual agent behaviours.

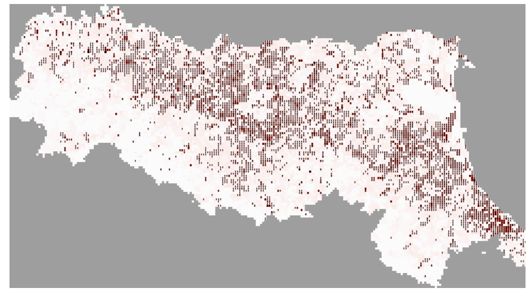

Fig. 5. Simulated photovoltaic penetration in the ER region

In the energy policy scenario, social simulation can be used for assessing the social impact of policy instruments and mechanisms. In fact, not only economic aspects affect the agent decision in perceiving an energy efficient behaviour. Social aspects [12] play an important role such as environmental sensitivity, feeling of belongingness to a group, feeling of freedom from energy providers, importance of creation to agent, trust in the government and future and perceived bureaucracy. These aspects, together with economic and financial considerations can be used to model agents that react to energy policy instruments and mechanisms to come up with a simulated renewable energy diffusion (see figure 5) corresponding to instruments and mechanisms.

This component is extremely computational demanding, needing to simulate a huge number of agents acting, interacting and deciding in a complex environment. High performance computing might be a driver for obtaining realistic and accurate simulations.

2) Mechanism Design: To take into account economic aspects one could assume that agents are all self-interested and rational utility maximizers In this setting one can apply the solution concepts of Nash Equilibrium to predict expected outcomes. This is an attractive concept for policy makers because it can aid the predictability of novel economic policies or initiatives. A seminal result known as the *Revelation*

Principle states that, no matter the mechanism, a designer concerned with efficiency need only consider equilibria in which agents truthfully report their "types" that signify their private valuation for an item [13]. Cleverly designed economic mechanisms (or auctions) can allocate resources and determine payments that are resilient to manipulation. The design of subsidy schemes to support the construction of public goods is particularly challenging [14]. Our setting involves a possibly large number of agents and a set of renewable technologies so tractability concerns must also be borne in mind [15]. The key design challenge concerns the *free rider problem* and consequent under provision of public goods. For example, in first price auctions previously conducted in the Emilia-Romagna region, participants that wished to acquire a photovoltaic device without government aid had an incentive to underreport their valuation to receive a subsidy.

Mechanism design is a game of private information in which a single central agent, the "center", chooses the payoff structure. Agents report a type to the center that they may choose strategically so that it is different from their true value. After the reporting phase, the center determines an outcome. The outcome consists of an allocation and a payoff. The center typically wishes to fulfil a *social choice function* to map the true type profile directly to the allocation of goods transferred, whereas a *mechanism* maps the reported type profile to an outcome.

V. Discussion and Open Issues

Enabling technologies for each step of the ex-ante policy making process have been devised, but a fundamental issue concerning their integration is still open. While planning and strategic environmental assessment are merged in a single model, the implementation strategy still needs to be integrated in the overall process. We have devised two main research directions described in [16] one using machine learning for extracting from the simulator causal relations between policy instruments and their effect on the energy market and the other based on interleaved execution of the simulator and the decision making component to reach an equilibrium point.

A second aspect that has not been considered in the paper, but is extremely important, is the role of social participation to policy issues. A number of e-Participation tools have been developed and are currently used by the Emilia-Romagna region to enable public consultations. Clearly, citizen participation in the definition of public policies might be fostered by the use of mobile services, such as visualization of big amount of data in an intuitive way or the possibility of customizing the participation actions only in some contexts. Another way to use opinions from citizens without the need of their direct involvement is to use opinion mining [2] on data extracted from public blogs, forum and press. Social networks could also play a foundamental role to understand not only opinions, but also arguments [17] supporting them. People opinions might represent an extremely important information for policy makers and might influence not only the planning process, but also the implementation instruments and mechanisms.

Acknowledgment

The author is partially supported by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n. 288147. This paper is a summary of a research activity developed within the project and has been developed with the collaboration of Tina Balke, Federico Chesani, Sabrina Franceschini, Simone Gabbriellini, Marco Gavanelli, Nigel Gilbert, Alan Holland, Anna Maria Linsalata, Barry O'Sullivan, Attilio Raimondi, Fabrizio Riguzzi, Daniele Sangiorgi, Tobias Ruppert, Luis Torgo, Paolo Torroni, Don Webster, Tony Woods. The coaxial matrices have been provided by ARPA Emilia Romagna, thanks to Paolo Cagnoli.

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