Renewable energy systems: A societal and technological platform

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Abstract

Today, the analysis of renewable energy places the emphasis on the technological and economic attributes with social and environmental impact assessment providing for a rather static, narrow frame of analysis. The participation and response of social actors and other stakeholders is usually of a traditional type, with consultation documents and public meetings, collection of complaints and suggestion schemes. This often encourages parochialism and an over-concentration on relatively trivial issues. It is, therefore, imperative to establish a new participatory planning platform to incorporate the wider socio-economic aspects of renewable energy systems and to provide for an operational analytical decomposition of them. In this work the issue of decomposition analysis is clarified, and a new agenda for the societal and technological decomposition analysis of renewable energy systems is developed. A case study is disclosed to present the relevance of the established platform for integrated (renewable) energy systems planning. Innovative aspects comprise of the simultaneous inclusion of decision analysis and social acceptance methods and tools in concert with the related public participation techniques.

Keywords: Renewable energy systems; Decomposition analysis; Socio-economics; Technology; Public participation; Wind energy

1. Introduction

Today, renewable energy systems’ analysis has the emphasis on the technological and economic attributes with environmental impact assessment providing for a rather static,
narrow frame of analysis. The response of actors and other stakeholders is usually of a traditional type, with consultation documents and public meetings, collection of complaints and suggestion schemes. This often encourages parochialism and an over-concentration on relatively trivial issues.

For the various renewable energy technologies (RETs) projects and programmes in particular, there is sometimes only a loose connection with the public, through a constricted, limited-scope public participation process [1]. The available social tools, like cost-benefit analysis (CBA), multi-criteria analysis (MCA), etc. express the general climate in which they have been developed and applied [2].

Such form of participation initiatives encourage slack practices and creeping-in of situation of conflict, while at the same time deprive the decision process from valuable input coming from the people directly involved in the good performance and success of RET projects [3,4]. Past experience has shown that geothermal power, for example, faced insurmountable local opposition that, many times, lead to project abandonment [5].

One of the ways ahead might be to support, help and educate relevant key players and participants such as local authorities, developers and investors, as well as to inform the public in general, in order to increase their awareness for renewable energy sources (RES) [6]. This need is accentuated by the lack of proper understanding of factors that determine the actual cost/benefits of renewables. That is due to the fact that only limited attention has been devoted to developing integrated methodological frameworks and tools, appropriate to measure the socio-economic impetus for RET deployment [7]. It is crucial, therefore, in order to exploit the vast potential of RES to diffuse appropriate technological solutions easily adopted in different social and cultural contexts and level of liberalized markets.

This paper describes this new agenda for renewable energy planning which combines societal with technological decomposition analysis in order to provide for an integrated outline for new energy systems design. Next section shortly presents the current situation in (participatory) renewable energy planning, giving emphasis on particular public attitudes and level of related social acceptance. Subsequently, the issue of decomposition analysis is clarified and a way to practically adopt it in contemporary energy planning is launched. A case study regarding the development of a wind park in Greece is presented to exhibit the applicability of the proposed platform. We close the paper with some discussion and conclusions.

2. Current situation

Up to now reactions of the general public towards renewables have been studied on an ad-hoc basis, with a lack of a wider perspective and with short-term focus. It also involved particular technologies and energy management practices, like biomass projects, wind farm installations, rational use of energy and conservation in households, etc., without an integrated framework of analysis [8]. The associated social processes (e.g., knowledge diffusion, local cultural identities, particular belief systems and the social and behavioural aspects of energy consumption) have not been given their due importance; only implicitly they were included in related decision support tools [9].

Particularly for energy planning, the dispersed nature of energy investments obeys wider rules related to the deregulation of electricity and natural gas markets, environmental norms, enhanced mobility of human resources and scrupulous economic and social priorities, and that form the wider scene of energy–environment–economic policy. It is
thus mandatory, when considering the penetration of RETs to take into account the individual characteristics and the particular interests of the decision making groups responsible for their successful implementation. Such groups, e.g. local people, consultants, environmentalists, manufacturers, investors, mayors, regional governors, etc. have to plough common ground in order to come to a consensus that is really a compromise solution amid conflicting interests and priorities [10].

In most cases, however, promotion of RES systems assumes that the behaviour of the population concerned is one of passive acceptance. Such practices have lead in the past in failures, conflicts, and slack attitudes jeopardising the overall strategic goals of sustainable development. This is reflected to the overall time required for the commissioning of a RET project and especially for the licensing stage where a lot of objections and subsequent appeals occur (Fig. 1). The data presented are based on our experience with wind, hydro, PV and geothermal projects in Greece, Netherlands and Spain [11].

It is evident that renewable energy systems will become a well-established paradigm only if a social acceptance environment, catering for their technological and management features, is created and maintained throughout their whole lifetime. Besides, it is often the case that the whole picture becomes blurred as the various actors involved get entangled in conflicting issues such as their concern for the environment and urge to do something about it, the need for regional development and the fascination with new technology and the new know-how. These come into contrast with NIMBY-type reactions that often arise, undermining efforts and wasting financial and human resources.

It is, therefore, vital to establish a new planning platform to incorporate the socio-economic aspects of renewable energy systems in conjunction with their technological attributes and to provide for an operational analytical decomposition of them. This work describes the essentials of such an agenda.

3. Decomposition analysis of renewable energy systems

In order to analyse, evaluate and improve a complex system one could decompose it into separate functional units with no independent variables in common. This decomposition analytical approach corresponds to a disaggregation of the entire system into non-directly interacting subsystems with independent attributes (Fig. 2).

The appropriate level of decomposition depends on the character of the system under consideration and the availability of information [12]. Ideally the final disaggregated indicators should be readily assessed. For energy systems several problems emerge due to the fact that many of their elements are not subject to quantitative evaluation and have
been excluded from the majority of impact assessments in the past, although at the local level they may be noteworthy [13]. In the case of RES systems, due to their enhanced social nature, the related socio-economic impacts typically differ according to the technology selected, local economic structures, cultural identities, environmental conditions, and social profiles.

The derivation of the above forms the basis for the decomposition analysis of RES systems, which includes (Fig. 3):

A. the RET level (project/process/service), and
B. the Societal level, i.e. the (participatory) decision-making process.

Thus, to encourage integrated RES systems design that incorporates sustainability thinking explicitly, it is useful to establish a systematic protocol that addresses both the attributes of sustainable RETs coupled with the socio-economic aspects of the related decision-making process.

More specifically, the decomposition of sustainable RETs includes the assessment of their impact in the dimensions of sustainability, namely economy, environment, society and resource base [14]. This analysis could provide for an integrated sustainability design module (Fig. 4).
The socio-economic decomposition of the decision-making process includes the public participation techniques and the analytical decision and social acceptance measurement tools such as CBA, MCA and others (Fig. 5).

The multi-criteria methods could be used as models and tools for (indirect) social acceptance measurements and may well include a diversity of families of methodologies such as Multi Attribute Utility Theory—MAUT [15], Outranking methods [16,17], Programming methods [18], and other methods, like the Analytic Hierarchy Process—AHP [19], Novel Approach to Imprecise Assessment and Decision Environments—NAIADE [20], Stochastic Multi-objective Acceptability Analysis—SMAA [21], etc.

The public participation techniques may include methods like preference-weights elicitation, opinion surveys, community advisory boards, focus groups, citizen juries, etc.
[22–24], and their particular applications in energy and environmental planning and decision making [25,26].

It is expected that this societal and technological decomposition of renewable energy systems and projects will improve their social acceptability and profile. At the same time essential elements regarding the actual costs and benefits of RES could be disclosed and in cases where the development of RETs is socially and technically justified a boost in their deployment could be launched. The currently proposed platform could thus promote and enhance RETs’ penetration, overcoming current difficulties and barriers arising from incomplete knowledge and increasing the awareness of parties involved. Furthermore, it will analyse and establish the socio-economic aspects of RETs and rational use of energy (RUE) systems at the project- and programme-level taking into account the steps of the decision-making process. The social acceptance measurement tools and public participation techniques will be adapted in order to tackle the complex attributes of RETs and RUE systems, to assess their tangible socio-economic diffusion potential, and to reveal ways of achieving actual legitimacy by incorporating the public in the planning process. An illustration of the above is presented in a case study in the next section.

4. Case study: the development of a wind park in Troizina, Greece

In this section, a real case study is disclosed to show the applicability of the proposed societal and technological platform for renewable energy systems. The case study concerns the development of a 31.45 MW wind park in the municipality of Troizina in the northeast coast of Peloponnese, Greece (Fig. 6).
Currently ‘Elliniki Technodomiki Energiaki’ S.A., a company that is activated in wind energy exploitation and technology, is planning to install a wind park of 31.45 MW at the mountain of ‘Aderes’ behind the municipal department of Galatas. Totally 37 W/Ts of 0.85 MW each are to be installed. The whole wind park is situated within the administrative borders of municipality of Troizina.

The wind park is currently just before the construction process. The life cycle of the project so far and the associated time needed are presented in Fig. 7.

In order to perform an integrated societal and technological evaluation of the proposed venture, a decomposition analysis of the proposed project is launched, according to the theoretical platform presented earlier in the paper. This breakdown analysis entails different dimensions, criteria/attributes and finally indicators ready to be assessed (Fig. 8).

Pertinent stakeholders include the investor, the mayors of the nearby municipalities of Troizina and Poros, the Regional Authorities of Piraeus (very much involved in the license permits procedure) and two environmental NGOs, namely the Hellenic Scientific Association of Wind Energy and Greenpeace Hellas. The proposed project would be assessed in comparison with four alternative projects, with installed power from 0 to 74 MW. Following the theoretical agenda described earlier, an overall system analysis for the Troizina wind park can be established (Fig. 9).

### Troizina wind project lifecycle

<table>
<thead>
<tr>
<th>Planning</th>
<th>Design</th>
<th>Licensing</th>
<th>Construction</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Initial data collection</td>
<td>- Design of wind park</td>
<td>- Application preparation</td>
<td>- Installation of WTs</td>
<td>Operation starts within next months</td>
</tr>
<tr>
<td>- Wind potential estimation</td>
<td>- Selection of W/Ts</td>
<td>- Accompanying documents</td>
<td>- Construction of roads</td>
<td>- Maintenance</td>
</tr>
<tr>
<td>- Setting of the project</td>
<td>- Environmental Impact Assessment</td>
<td>- Regulatory Authority for Energy</td>
<td>- Connection to the grid</td>
<td>- Costs</td>
</tr>
<tr>
<td>- Preliminary process for license permits &amp; eligibility of proposal</td>
<td>- Public consultation</td>
<td>- Independent evaluation of proposal</td>
<td>- Peripheral buildings</td>
<td>- Control</td>
</tr>
<tr>
<td>- Consultation with the nearby municipalities of Troizina &amp; Poros</td>
<td>- Regional Authorities of Piraeus</td>
<td>- Comparative evaluation of proposal</td>
<td>- Related infrastructure</td>
<td>- Safety</td>
</tr>
<tr>
<td></td>
<td>- Transmission system &amp; interconnection capacity</td>
<td>- Objections rising</td>
<td></td>
<td>- Fine tuning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Positive opinion of RAE</td>
<td></td>
<td>- Fees to local municipalities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ministry of Development</td>
<td></td>
<td>- Employees</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Installation license</td>
<td></td>
<td>&quot; …</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Production license</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Actual time needed

<table>
<thead>
<tr>
<th>Planning</th>
<th>Design</th>
<th>Licensing</th>
<th>Construction</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 months</td>
<td>8 months</td>
<td>3 years</td>
<td>1 year</td>
<td>15-20 years (estimated)</td>
</tr>
</tbody>
</table>

Fig. 7. Troizina wind project, Greece; lifecycle and indicative time needed for its implementation.
## Renewable Energy Systems; decomposition analysis of the Troizina wind project

<table>
<thead>
<tr>
<th>Dimensions, Subsystems</th>
<th>Energy – resource base</th>
<th>Economy</th>
<th>Environment</th>
<th>Society</th>
<th>Technology</th>
</tr>
</thead>
</table>

### Criteria, Attributes (examples)

- **Energy – resource base**
  - Reduction of fossil fuels imports
  - Amount of renewable electricity produced

- **Economy**
  - Installation & operational costs
  - Entrepreneurial risk

- **Environment**
  - Land use
  - Noise creation
  - Aesthetics
  - Contribution to mitigating climate change

- **Society**
  - Employment creation
  - Public acceptance

- **Technology**
  - Reliability & safety of the technology selected and the emergent electricity system

### Indicators (examples)

- **Energy – resource base**
  - Tons of oil equivalent saved per year [toe/yr]
  - kWh produced per year [KWh/yr]

- **Economy**
  - \( \text{\$} / \text{kW} \text{ & } \text{\$} / \text{kW} \text{ Qualitative, semi qualitative index} \)

- **Environment**
  - \( m^2 \text{ Decibel added x population affected [dB(A) x no of people]} \)
  - Qualitative impact scale
  - Tons of CO2 emissions avoided

- **Society**
  - No of jobs created [man days/year]
  - Qualitative scale

- **Technology**
  - Qualitative scale

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**Fig. 8.** Renewable energy systems; decomposition analysis of the Troizina wind project.

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## Troizina wind park systems analysis

### A. RET level

- **Project/Process/Service**
  - **Project:** Wind park, electricity grid lines, secondary roads, transmission stations, related infrastructure...
  - **Process:** Production of electricity, control systems, maintenance of equipment...
  - **Service:** Lighting, cooking, electric devices, air-conditioning, etc.

### B. Societal level

- **Decision-making process**
  - Stakeholders
  - Public consultation
  - Objections, complaints
  - Positive/negative opinion
  - License permits
  - ...
### Wind park of Troizina: RET level - Decomposition Analysis

<table>
<thead>
<tr>
<th>No</th>
<th>Criterion</th>
<th>Explanation</th>
<th>Indicator – unit of measurement</th>
<th>Examples – Remarks – Comments - Questions to be addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.1</td>
<td>Amount of imported oil avoided</td>
<td>Indicates the amount of fossil fuel burned to provide an equivalent service</td>
<td>Tons of oil equivalent saved per year [t/yr]</td>
<td>Expresses the reduction of amount of imported oil. It is assumed that the project substitutes an oil plant. Depends on the total installed capacity of the project and the overall conversion efficiency.</td>
</tr>
<tr>
<td>EN.2</td>
<td>Amount of electricity produced</td>
<td>Provides an index of the magnitude and real production capacity of the project</td>
<td>kWh produced per year [kWh/yr]</td>
<td>✅</td>
</tr>
</tbody>
</table>

#### Economic attributes (EC)

| EC.1 | Return on investment – pay back period      | Ratio of the estimated profits per year to the initial invested capital       | No of years                      | Provides an indicator of the profits expected from the venture. What is the appropriate time horizon? What would be the discount rate? |
| EC.2 | Net present value of the investment         | Annual savings or costs from the project divided by the discount factor        | €                               | ✅ |
| EC.5 | Community economic indicator                | Net economic benefit for the municipality, as paid by compensative benefit     | €/year                          | For Greece this is equal to 2% of project net revenue. It takes into consideration the community benefits due to individual option. |
| EC.6 | Entrepreneurial risk                        | Expresses the possibility of total project failure                            | Qualitative – semi qualitative index (min: 1, max: 10) | Risk items to be considered include the uncertainties associated with the introduction of a new product, new technology, any future unexpected changes and the level of initial investment. |

#### Environmental attributes (ENV)

| ENV.1 | Land use/compatibility with other activities | Land occupied by the project                                                  | km² or m²                        | Straightforward indicator assessment. Land is required for other uses (cities, roads, recreation, farmland, grassland, industries, etc) |
| ENV.2 | Noise creation                              | The total noise impact is calculated by multiplying the incremental noise level with the population affected | Decibel added x population affected [dB(A) x no of people] | Depends on the proximity of the project to villages and suburbs and on the design parameters of the project. Indicative values: 52 dB(A)/MW wind. Noise standard: 45 dB(A) in urban areas. |
| ENV.3 | Visual impact - aesthetics                  | Attributes to be taken into consideration include scenic beauty disturbance, wilderness, special area of conservation, amenity use of designated site | Qualitative impact scale         | Depends on the original situation of the area, the remoteness, isolation, natural beauty, etc. |
| ENV.4 | Electricity networks and access roads        | Construction of new electricity networks and access roads                     | km of new network and roads      | Emission occurs due to construction of roads, and networks, reduced amenity, landscape degradation. However new roads can be used by local farmers, grazers and firemen. |
| ENV.5 | CO₂ reduction potential                     | Indicates the contribution of the project to tackling climate change         | Tons of CO₂ emissions avoided    | Depends on the fuel to be substituted. |

#### Social attributes (S)

| S.1 | Employment creation                         | It expresses the potential for enhancement of the local workforce            | No of jobs created [men days per year] | What is the current level of unemployment in the area? It is considered as an important means to increase public acceptance. What is the general political climate? What is the level of satisfaction of local opinion leaders? Do the people find appropriate the implementing organization? Overall, it is considered as prerequisite for successful implementation. |
| S.2 | Public acceptance                           | Indicates the potential for social conflict creation. It depends strongly on the aggregate environmental impact and employment creation. | Qualitative scale                 | ✅ |

#### Technological attributes (T)

| T.1 | Reliability and safety                      | Qualitative scale                                                           | Refers to: the maturity of the technology used, risk of a serious accident, capacity to provide electricity when needed, the stability of the network. | ✅ |
B. Trozina wind park: Societal level—socio-economic decomposition of decision-making

<table>
<thead>
<tr>
<th>Decision analysis &amp; social acceptance Methods &amp; Tools</th>
<th>Public participation Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Multi-criteria Decision Analysis</td>
<td>- Bilateral interviews.</td>
</tr>
<tr>
<td>- PROMETHEE II method</td>
<td>- Weights elicitation</td>
</tr>
<tr>
<td>- Ranking of alternatives</td>
<td>- Iterative procedure</td>
</tr>
</tbody>
</table>

Fig. 11. Trozina wind park: Societal level—socio-economic decomposition of decision making.
The decomposition analysis of the project at the technological level is presented in Fig. 10. Particular evaluation criteria (17 in total), indicators, explanations, questions to be addressed and comments/remarks are also included.

The decomposition analysis at the societal level (decision-making process) is outlined in Fig. 11.

This socio-economic decomposition of the decision-making process encompasses the PROMETHEE II multi-criteria method jointly with bilateral interviews with the identified stakeholders. In Fig. 11 the ranking of the alternative scenarios for the Decision-Maker Municipality of Troizina (as expressed by the mayor) is also presented next to the related weights of the evaluation criteria. Further details of the procedure can be found in the relevant ‘MCDA-RES’ project web-site (www.exergia.net/mcda). The bilateral interviews with the stakeholders conclude with the elicitation of their weight factors towards the evaluation criteria and an iterative procedure is then initiated to improve the consistency of the whole approach. It was found that the original proposed scenario of the investor was finally appropriate for implementation.

This case study reveals the ability of the developed societal and technological platform for renewable energy systems to provide a transparent framework for decision aiding in such situations, where diverse audiences of stakeholders’ takes part, different criteria are taken into consideration, and several alternatives are compared.

5. Discussion and conclusions

In the last decade a substantial diffusion of RETs has been materialised. In many cases, however, this growth is not yet self-sustained. Apart from a lack of cost competitiveness, there are numerous socio-economic and institutional barriers that need to be identified and addressed under a clear analytical agenda.

At present, planning for the promotion of RES is characterized by a wide range of approaches and diversification between the various contributing elements, such as:

- dispersed knowledge regarding the social acceptability of potential policy measures,
- ensuing public participation,
- different legislative and normative procedures,
- lack of awareness of possible environmental, economic, and social benefits,
- need of coordination and good practice dissemination,
- technical and scientific expertise (energy experts, decision analysts, regional planners, etc.).

Despite the fact that considerable research efforts and resources have been employed, it seems that a lot of action needs to be undertaken relevant to the detailed decomposition of the socio-economic and wider societal issues of RES systems. This emerged interest is currently creating a need for a substantial amount of information gathering, processing, communication and dissemination. The emergence of the situation is augmented by the need to speed up activities for fulfilling Kyoto commitments leading to a vast requisite for a better understanding of the current situation and future prospects in order to accelerate RES penetration.

This extends not only across different countries but also across different bodies, disciplines, and levels of environmental sensitivity and technology acceptance. It is
therefore mandatory to establish the necessary policy portfolio in order to address problems that emerge from the above issues.

This paper provides some insights relevant to the sustainability assessment of renewable energy systems in such a way that it will enable a breakdown analysis of RETs in conjunction with a socio-economic decomposition of the related decision-making process. Thus, the broad range of technological, economic, environmental, resource and social participation factors can be simultaneously considered and an operational compromise between them may be achieved.

The incorporated case study illustrated comprised of the decision-making process for a wind park project in the municipality of Troizina, Greece. Different stakeholders have been identified and alternative potential projects have been formulated by means of public consultation and bilateral meetings with the people involved in the decision-making process. The technological decomposition analysis of the project revealed 17 evaluation criteria and related indicators were established, on a quantitative and qualitative basis. Formal weights elicitation procedures have been applied to assess the stakeholders/decision-makers preferences between the criteria. The multi-criteria decision analysis PROMETHEE II method has been chosen due to its ease of understanding, simplicity in use and clear visualization ability for results presentation. It was proved that the societal and technological platform developed for decision-aid and integrated evaluation of renewable energy systems could help the participants in reaching a compromise solution.

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