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A methodology for validating the renewable energy data in EU

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Abstract

The multidimensional character of renewable energy sources (RES) necessitates the collection of a number of related data in order to support EU policy needs. Apart from the technology and techno-physical data also socioeconomic (e.g. employment, turnover) data and R&D expenditures are of critical relevance. The monitoring of the above RES data with respect to the existing targets for RES is of significant importance. In addition to this, even though significant data gathering efforts have been implemented, a lot of fragmented data and deduced findings are currently available, which sometimes lack consistency and verification. As a result, RES data validation and completion capacity is needed in the framework of the European Union (EU) energy policy. In addition to this, agreed and validated RES data can help energy policy makers and relevant stakeholders answering to pressing energy socio-economics' and sustainability issues. In this context, the main aim of the paper is to present a reference methodology for validating the RES Data in the EU. The development of the methodology is mainly based on the review of existing methods and ends up with recommendations for improvements in RES data aggregation and statistical interpretation, taking into consideration the related analysis of statisticians, energy technology experts and energy socio-economists.

Keywords: Renewable energy sources data; Validation; EU

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1. Introduction

The energy policy in the European Union (EU) is strongly driven by the twin objectives of sustainability (including environmental aspects) and security of supply. Implementation of environmentally friendly energy options, such as renewable energy sources (RES) is key means of satisfying these objectives [1]. According to the available data by various providers, even though RES have increased their contribution to the energy production in EU, they have not yet achieved a satisfactory introduction to the energy market, in contrary to their significant perspectives. In particular, for both EU-15 and the 10 new Member States the renewable energies share in the primary energy consumption is estimated at 5.6%, with an average share of the 10 new Member States amounting to 4.9%, while for the "old" EU-15 their share reached 5.7% in 2004. The accession of the 10 new Member States did not change the fact that the biomass is by far the leading RES used in the EU, with a share in the primary energy production from renewable sectors of 65% [2]. In addition to this, photovoltaics in on-grid applications achieved high growth rates of more than 30% over the last 3 years, while solar thermal electricity is in the phase of demonstrating its potential on an operational scale of 100 MW and more [3]. Moreover, the EU has installed wind energy capacity equivalent to 50 coal fired power stations in 2005, with the costs being halved in the past 15 years [4]. Concerning Research and Development (R&D), in most EU countries, the R&D for RES is funded with 20–40% of the total energy research budget [5]. The EU's market has an annual turnover of €15 billion (half the world market), employs some 300,000 people, and is a major exporter [4]. Furthermore, a study has forecasted that employment in this energy sector could reach over 900,000 in Europe by 2020, with the majority of jobs created in bio-energy technologies together with biomass fuel provision [6].

Based on the abovementioned, the multidimensional character of RES necessitates the collection of a number of related data, apart from the technology and techno-physical data also socioeconomic (e.g. employment, turnover) data and R&D expenditures are of critical relevance. In this context, policy-makers as well as individuals in the democratic society will be able to trigger specific answers to urgent questions taking into consideration not only the economic feasibility of the examined options but their social and environmental acceptability as well. In addition to this, the monitoring of the RES data with respect to existing target setting is of significant importance. Significant data validation and data completion capacity is needed in the framework of the EU sustainability policy. Already the White Paper [7] demanded a constant monitoring of activities in order to follow closely the progress achieved in terms of RES penetration. Moreover, the importance of improved co-ordination of programmes and policies of the Community and the Member States so as a unified acceptable system of statistics to be developed, was underlined. The Directive of the European Parliament and the Council [8] on the promotion of electricity produced from RES in the internal electricity market specified targets for each Member State. Furthermore, the Commission's Green Paper [9] pointed out the crucial need for improved RES and the important role of (data) monitoring systems. In the most recent Green Paper [4] it is clearly stated the need for monitoring progress and identifying new challenges and responses on all aspects of EU energy policy and supply patterns on EU energy markets.

In addition to this, even though significant data gathering efforts have been implemented, a lot of fragmented data and deduced findings are currently available, which lack consistency and verification. Often are even missing clearly defined criteria for correct data visualisation and interpretation. In addition to this, data on Europe's RES implementation are not yet sufficiently interpreted in its socio-economic context of human resources, policy measures efficiency, industrial stakeholders' and customers' choices, world-wide societal costs or environmental impact. Where this was already done in parts and with highly specific approaches, the results appear too often as dependent on non-typical input data. Also often the "consumers" of knowledge created this way are irritated by partially controversial results, e.g., from different modelling, and even different plain statistics. Another need is the lack of consistent historical data synopsis on all energy technology R&TD expenditure in the last decades (from the 1960s until today). This gap has caused a very nebulous picture about the efficiency of different RES technology options, when looking at their derived societal or economic benefits (wealth production, job creation, environmental relief, impact for sustainable development, etc).

In this context, the main aim of the paper is to present a sustainable reference methodology for validating the Renewable Energy Data in the EU. The development of the methodology is mainly based on the review of existing methods and ends up with recommendations for improvements in RES data aggregation and statistical interpretation, taking into consideration the related analysis of statisticians, energy technology experts and energy socio-economists.

The necessity for completed and validated data is particular important for a number of stakeholders, which can be defined in three "layers", going virtually from experts to public:

- *Suppliers*: These are mainly institutions providing data, private or public, regional, national, or international. They may range from national ministries, industrial or trade organisations, NGOs, to singular experts.
- *Users*: These are decision makers for whom data will have to be crafted to make better informed decisions, such as those in policy making and business who make the decisions related to implementation of new technologies. This layer comprises policy-makers at EU, national and also regional level, e.g., members of Parliaments (up to EP-level), of the Committee of the Regions, etc.
- *Concerned public*: These are concerned citizens primarily on technology options and development, which can find their way to new opportunities.

Apart form the introduction, the current paper is structured along seven parts: Section 2 presents the approach adopted in the current study for validating the RES data as well as the basic steps followed. Sections 3–7 are devoted to the presentation of the techno-physical, potential, socio-economic, R&D expenditures and technology data validation, based on the methodology presented in the previous section. Finally, in the last section the main points drawn up from this paper are summarised.

2. The approach

The analysis that follows is highly based on the context of an ongoing project funded by the programme FP-6 of the European Commission (EC). Its basic goal is the enhancement of the timely availability, validation and traceable quality of data concerning renewable energy. The final aim is the establishment of a "one-stop-shop" for the EU for policy and decision-makers, serving with unbiased and more complete and validated data on green energy technologies. In particular, the approach was based on the selected information and data by publications of international organisations, the kind contribution of experts, as well as the results of the implemented events. It is structured along the following four steps.

- *Formulation of the references' categories*: A number of individual papers exist in the international literature that focuses on different aspects of the RES data. In particular, technology data concerning learning rates are increasingly being incorporated in models to assess long-term energy strategies and related greenhouse gas emissions [10]. Life cycle assessment (LCA) for RES plants, aiming to synthesise the main energy and environmental impacts is also being proposed [11]. New participatory planning platforms to incorporate the wider socio-economic aspects for RES [12] and policy learning to study ways to support RES [13] exist in the international literature. In addition to this, the impact of R&D on price reduction [14], performance indicators of the expenditures in research, development and demonstration (RD&D) for RES [15] as well as the economic benefits from R&D [16] are proposed, evaluated and discussed. The energy potential is also being calculated by technology and by region, to identify which RES are likely to be important globally, regionally, locally or not at all over the next 35–40 years [17]. In this context, the required RES data to be investigated towards the development of renewable energy worldwide were categorised to (a) techno-physical, (b) potential, (c) socio-economic, (d) R&D expenditures and (e) technology data.
- *Review of methods*: An analytical review of existing methods for collecting RES data, based on the experience from the common reporting rules from the international institutions, literature and from statistical databases (international, EU and national) was implemented. The literature review was based on the existing statistical offices, international and national energy agencies and also from the most competent research teams, who have a clear idea about RES state-of-the-art.
- *Definitions and comparison*: This step played a significant role in the development of the current methodology. More analytically, an establishment of a common understanding between statisticians, energy technology experts and energy socio-economists for the most important parameters of the RES data assumptions was implemented. As a result, the identification of data as well as structuring gaps (i.e., lacking data for certain regions, certain technologies, certain market segments or participants) was implemented by comparing the previously analyzed methods.
- *Presentation and discussion of the results*: The last step included a final stakeholders' workshop (June 2006, Paris—France), under the umbrella of International Energy Agency (IEA), where the specific references' categories as well as the definitions and categories and views of the related operators and stakeholders have been presented, discussed and finalised. During this workshop, a distinguished audience constituted of managers of the above and other relevant organisations, participated and supported the fruitful dialogue regarding enhancing the reference methodology of renewable energy in the EU. As a result, a harmonised set of data-gathering categories, aggregation levels and best practice definitions in order to overcome inconsistencies taking into consideration the current status in the national, European as well as international level.

3. Techno-physical data

3.1. Review of methods

The present data gathering methods, existing assumptions and definitions for techno-physical data approaches are briefly described in the following paragraphs.

- *OECD/IEA, EUROSTAT and UNECE*: At European level, data consolidation and harmonisation of data collected by the respective Member States is put into practice by EUROSTAT (Luxembourg), the statistical body of the EU, by the Statistical Division of the Economic Commission for Europe of the United Nations (UNECE, Geneva), and by the OECD/IEA, International Energy Agency (Paris). In particular, as a result of close co-operation and co-ordination of statistical activities in the field of RSE a joint questionnaire between the UNECE, the IEA and EUROSTAT was implemented in August 2000 (Annual Renewables and Waste Questionnaire) [19]. Improved data collection methods are needed especially for off-grid renewable and waste production, e.g., small wind turbines and solar panels [18].
- *IEA RES-statistics*: For OECD member countries the most important RES-data are compiled in the annually produced IEA Renewables Information [20]. This publication includes general notes and definitions, notes on RES, country notes and geographical coverage. Statistics about electricity from fuel cells using hydrogen from RES as well as non-renewables fuel cells are not implied due to lack of reliability. The data included concern the set of main indicators (Energy supply, GDP and Population) considering percentage of RES and the share of electricity produced from RES, the status of net electrical capacity of RES by type of fuel, the gross electricity generation from RES, the gross heat production from RES and the balance for different products (primary energy supply, transformation and final consumption of RES). For some sub-sectors a lack of reliable statistics is conceded and explained. Non-commercial biomass is included in IEA-definition of RES but data are not complete. Country notes are necessary to pay attention when using national aggregates. The IEA Energy Statistics Division (2004) [21] noticed that data presumably are more accurate for electricity and heat production and electricity generation capacity than for supply and final consumption of RES and waste.
- *EUROSTAT RES-statistics*: In the case of EU member countries the responsible statistical agencies using the joint questionnaire are requested to transmit the completed questionnaire to EUROSTAT. For methodological comparisons one of the most frequently used publication of EUROSTAT Energy—Yearly Statistics [22] is chosen. This yearbook gives an overall view of the trends for RSE and provides data for primary production, inputs to electricity and heat production, final consumption of RES by sector and sources, electricity generation from RES, electricity capacities of RES, liquid bio-fuels and solar panels.
- *Other sources*: Potential other sources are The European Barometer of Renewable Energies in the scope of EurObserv'ER Project as a tool for monitoring the different RES and data from industrial sector organisations such as Wind energy data published by EWEA and Active solar thermal data published by ESTIF. The data given by these publications are topical. On the other hand, the methodology used is intransparent and cross-checks therefore are uncertain.

3.2. Definitions and comparisons

The above-mentioned national and international organisations and agencies still use different definitions of RES techno-physical data. However, in accordance with the EU-Directive 2001/77/EC the following RES data categories should be considered:

- *RES-electricity (E) capacity and production data*: Hydropower (large (>10 MW) and small (<10 MW)) (excl. pumping), photovoltaics, solar thermal electricity, wind energy (onshore, offshore), biogas (including landfill gas, sewage gas and gas from animal slurries), solid biomass, biodegradable fraction of municipal waste, geothermal electricity, tidal and wave electricity.
- *RES-heat (H) capacity and production data*: Grid and non-grid connected biomass (wood, agricultural products and residues), renewable municipal solid waste, biogas, solar collectors (grid and non-grid), geothermal (incl. ground coupled heat pumps).
- *RES-Transport (T)*: Liquid bio-fuels.

Following the above-mentioned categories, the following inconsistencies are most striking:

- In the Joint questionnaire of UNECE, IEA, EUROSTAT, data are to be reported by public plants and auto-producer plants. The EUROSTAT data include grid and non-grid heat. On the other hand, IEA statistics differentiates between CHP plants and heat only plants. Therefore, non-grid connected heat is not declared firsthand.
- Electrical capacities and generation from RES are not complete in the EUROSTAT publication. Data for geothermal and wind capacities and electricity generation are only compiled in the electricity balance and capacity statistics. EUROSTAT does not give the renewable share of municipal waste and no differentiation between CHP and pure power generation. IEA data contain no differentiation of small and large-scale hydropower. Generally, no differentiation between wind energy on- and offshore is given.
- The EUROSTAT heat production data from biomass seem not clearly defined. Apparently wood, wood-waste, total municipal solid waste and biogas are aggregated. In the case of electrical capacities and electricity generation biomass includes wood/wood-waste and (total) municipal waste. Biogas, sewage gas and landfill gas are generally not disaggregated.

4. Potential data

4.1. Review of methods

The guidelines for the assessment of potentials are presented by RES category in the following paragraphs [23].

- *Biogas*: Four different fuel categories should be considered: Farm slurries, agricultural residues, pasture residues and separated biodegradable fraction of municipal wastes.
- *Landfill gas*: The future potential of landfill gas is highly influenced by recent developments regarding waste treatment regulations as, e.g., given EU-wide by the

EU-directive on the landfill of waste [9]. In accordance with these regulations as implemented on a national level, primary potentials could be assessed. Next, in accordance with the above-mentioned waste treatment regulation, a certain percentage of waste to be landfilled has to be assumed. By applying figures with respect to gas rise, usability, energy content can be derived.

- *Sewage gas*: The approach to assess the future potential of sewage gas is recommended as follows: Water disposal per capita and/or the amount of sewage sludge (in total per region) can be used as indicator to determine the potential for sewage gas. Hence, the primary energy potential for sewage gas can be calculated by applying the specific energy content.
- *Solid biomass*: In general, solid biomass represents an energy source with a more or less strong limited potential—depending on region-specific conditions. Thereby, not only the primary energy potential is restricted. Moreover, the energetic use of biomass stands in competition to the material use and, in addition, competition occurs within the energetic fraction: Solid biomass like wood represents a traditional resource for heating, especially in rural areas.
- *Forestry products*: This sub-category covers all forms of wood directly harvested from forests. The additional potential can be derived from the unused net annual increment of forests, which are marked as available for wood supply. The unused net increment represents the difference between the net annual increment and the amount of fillings harvested. Hence, by applying a usability factor (roughly 70%) and density as well as specific heat value, the primary energy potential is calculated. It is important to note that in EU countries, in general, the growing stock of forests increases year by year.
- *Forestry residues*: The sub-category by itself includes the following fuel sources: Forestry wastes, solid industrial by-products, wood waste.
- *Agricultural products*: Straw represents an EU-wide common agricultural residue which can be used for combustion. The potential assessment is based on current production of cereals, yields differ by country in accordance with actual production data. Of course, for this fuel-category also region-specific can be considered.
- *Agricultural residues*: Straw represents an EU-wide common agricultural residue, which can be used for combustion. The potential assessment is based on current production of cereals, yields differ by country in accordance with actual production data. Of course, for this fuel-category also region-specific residues can be considered.
- *Biodegradable fraction of waste*: In order to derive the additional mid-term potential the amount of waste generated in the year 2030 must be estimated—by applying region-specific similar growth rates as observed in the past. Next, region-specific current waste treatment (incineration vs. recovery operations vs. landfilling) as well as implemented policy regulations has to be taken into account in order to provide stable forecasts of the future waste treatment. Finally, the potential for waste incineration occurs as residuum from other options. The biodegradable fraction can be estimated in accordance with the country-specific figures as presented in the PRETIR-study [24].
- *Geothermal energy*: As default, the primary energy potential of geothermal energy is subdivided into two parts: Low- (i.e. suitable for heat purposes) and high-temperature (suitable for both electricity and heat generation) geothermal resource. In general, the potential assessment has to be based on local studies or data, respectively.
- *Large-scale hydropower*: An additional realisable mid-term potential for large-scale hydropower is often hard to predict—due to severe constraints, i.e., the missing public

acceptance. Although hydropower is well exploited in Europe, the technical as well as the economic potential in some countries still is quite high—compared with other RES-E. In general, the potential assessment has to be based on local studies or data, respectively.

- *Small-scale hydropower*: In contrast to large hydro, data with respect to realisable potentials—considering also environmental constraints—have been well assessed in the past. A homogenous approach was undertaken within the project "BlueAge" [25]—where national experts derived in accordance with the applied approach of potential definitions reliable set of data representing country-specific potentials under consideration of economic and environmental constraints. In general, the potential assessment has to be based on local studies or data, respectively.
- *Photovoltaics*: In general, PV represents an energy source characterised by a large potential, which can be realised from a technical point-of-view. The recommended approach for the assessment of the (additional) realisable mid-term potential is based on the following categorisation of PV plant, PV on roofs (building integrated), PV on facades (building integration) and PV on fields (no building integration).
- *Solar thermal electricity*: In general, based on assumptions with respect to land use (0.5% of agricultural area, area factor) and country-specific data with respect to solar irradiation (direct irradiance) primary energy potentials can be assessed.
- *Solar thermal heat*: As default it is recommended to use a similar approach for the assessment of the primary energy potential for solar thermal heat as described for 'PV on roofs'.
- *Tidal stream*: The assessment of the future potential of tidal stream is accompanied by a set of difficulties. As the technological development is focussed on UK, for other parts of Europe no overall in-depth resource assessment has been conducted so far. Nevertheless, if available, the potential assessment should be based on local studies or data, respectively.
- *Wave energy*: The future potential of wave energy is indicated in many studies as huge, depending on roughness of sea, etc. Nevertheless, the technology is still not recognised by many countries, therefore EU-wide future projections of realisable potentials up to 2030 are difficult to provide. Recent assessments as provided, e.g. by Thorpe [26] have concentrated only on the UK. If available, the potential assessment should be based on local studies or data, respectively.
- *Wind offshore*: The overall technical potential for offshore wind energy seems to be huge in parts of Europe, especially in the North Sea—compare e.g. Greenpeace [27]—but several barriers have to be overcome, e.g. public acceptance, power grid constraints. Realisable potentials should be assumed "step-by-step"—after consultation of local experts, and keeping in mind important "constrain indicators" like, e.g., "percentage of wind power on total electricity consumption", "wind power (capacity) potential per capita". First, in accordance with geographical data, overall area-potentials can be assessed for the investigated region. Next, wind maps or wind data-sources such as the ones of Greenpeace [27] RISOE [28] shall be applied to the defined areas characterised by certain 'wind characteristics' (i.e. mean wind speed, roughness class). This finally enables the derivation electricity potentials.
- *Wind onshore*: The technical potential for onshore wind energy is high in various EU countries, namely France, UK—but several barriers have to be overcome, e.g. public acceptance, power grid constraints. Realisable potentials should be assumed "step-by-

step''—after consultation of local experts, keeping in mind important ''constrain indicators'' like, e.g. ''percentage of wind power on total electricity consumption'', ''wind power (capacity) potential per capita'', ''wind power (capacity) potential per land area. In this context, a set of bands—characterised by same wind conditions (i.e. described by full load-hours)—shall be derived—describing the overall mid-term generation potential from onshore wind.

4.2. Definitions and comparisons

The potential categories to be examined are described as follows:

- *Theoretical potential*: It represents the upper limit of what can be produced from a certain energy resource from a theoretical point-of-view, based on current scientific knowledge.
- *Technical potential*: If technical boundary conditions are considered, the technical potential can be derived. For most resources the technical potential must be seen in a dynamic context.
- *Realisable potential*: As already explained above, the realisable potential represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active.

5. Socio-economic data

5.1. Review of methods

A number of studies exist, which mainly focus on the results about the employment impact of RES implementation.

- *University of California-Berkeley*: A related study of the University of California [29] made a review and comparison of 13 independent reports, which analyse the economic and employment impacts of the clean energy industry in Europe and the United States. The study has examined the assumptions used in each case and developed a job creation model which shows their implications for employment under several energy scenarios. The study finds that greater use of renewable energy systems provides economic benefits through investment in innovation and through new job creation.
- *Wind Energy—Facts*: The estimation of employment in wind energy in the report of the published Wind Energy—Facts [30] is only related to the employment through manufacture, installation, operation and maintenance of wind turbines in EU countries. The calculation of the direct and indirect employment is based on national account statistics and input–output methodology used by economists. The basic idea of input–output methodology is to include the defects from suppliers of input to obtain better measures of the total effects of the activity. Direct and indirect employment effects are calculated based on the data from Eurostat's national account statistics. The direct employment related to operation and maintenance (O&M) is small compared to the direct employment associated with manufacturing and installation.

- *Renewable energy sector in the EU—its employment and export potential*: This report was prepared for use within the European Commission (DG Environment) [31] and provides a brief overview of the current status of renewable energy developments in the EU, together with an assessment of employment, manufacturing activity and export markets. It also gives an overview of the current status of renewable energy exploitation in Candidate Countries. The report analyses the study [32] carried out during 1998–1999 for DG XVII (Energy) of the European Commission aimed to provide a comprehensive analysis of the impacts of renewable energy deployment on employment from the present day to 2020. The report finds that principal opportunities for employment from the renewable energy sector occur in a wide range of areas: Manufacturing, project development, construction, installation, operation and maintenance.

5.2. Definitions and comparisons

Industrial factories produce technology for electricity (RESe) and heat (RESh) production from RES. Based on the above-mentioned review of methods, the needed RES socio-economic data to be considered for very clearly socio-economic effects of RES are the following:

- *GDP*: gross domestic product.
- *VA of industry*: value added of industry.
- *Turnover of RES industry*: turnover of industrial factories that produce technology for electricity and heat production from RES (RESe and RESh).
- *Turnover of RES energy sector*: turnover of the electricity and heat production plants using renewable energy sources (RESe) and RESh and biofuels refineries.
- *Employment in the RES industry*: number of employees in the industry of RES technology.
- *Employment in energy RES production plants*: number of employees in the energy sector working in the electricity and heat production plants using renewable energy sources (RESe) and RESh, biofuels refineries.

The socio-economic data for RES is not available in published official statistics, but there is data about energy production from RES. RES industry is a part of the environment industry as defined by the OCDE and Eurostat definition. Different institutions (IEA, UNDP, Eurostat and RES association (e.g. Wind, Biomass, PV, thermal solar technology) launched projects to identify and quantify the socio-economic and other impacts of RES production systems.

6. R&D expenditures

6.1. Review of methods

The present data gathering methods, existing assumptions and definitions for R&D expenditures approaches are reviewed with regard to the categories defined above.

- *IEA*: The data collected concerned the period 1990–2003 and were commissioned by OECD/IEA [33]. The disaggregation of governmental R&D data is rather high, since the IEA database includes the following categories: Solar Heating & Cooling, Solar Photo-Electric, Solar Thermal-Electric, Total Solar, Wind, Ocean, Biomass, Geothermal, Large Hydro (>10 MW), Small Hydro (<10 MW), Total Hydro, Total Renewable Energy. Only energy R&TD government expenditures for 15 Member States are provided.

- *REDS*: The data collected concerned the period 1992–2001 and were commissioned by the European Commission [34]. In the context of this database, analytical survey was elaborated for RD&D expenditure for RES in the EU and the 15 Member States. Data set was collected by using a questionnaire specifically designed. Together with the data, the subcontractors were required to provide a reliability index ranging from 1 (lowest confidence of the data supplied) to 10 (best confidence). The RD&D RES-database assembled is rather unique in Europe even if it is still incomplete. This tool enables evaluating national policies and to compare the development of RES in the European Member States. RES boundaries and priorities are: government national RD&D expenditures, government regional RD&D expenditures, other sectors of economy RD&D expenditures (private expenditures), government personnel involved in RD&D (by occupation and by qualification, measurement by headcount and by full time equivalent) and efficiency expenditures indicators. RES covered by this study are the following: biogas, biomass, geothermal energy, hydro energy, solar energy, tide, wave and wind energy.
- *EUROSTAT*: The data on R&D expenditures collected concerned the period 2001–2002 and were commissioned by Eurostat, the Statistical Office of the EC. European database is using Frascati Manual [35] methodology but data are not disaggregated. Furthermore budget-based data are given (not corresponding with the Frascati Manual definition of government allocations to R&D and subdivisions of technology like IEA database). In this Government Budget Appropriations or Outlays for R&D (GBAORD) [36] the technology is subdivided as follows: RES, solar thermal and photovoltaic energy, geothermal energy, water, wind and wave energy, research into biomass conversion and on the processing of waste from industry, agriculture and the domestic sector.
- *SENSER*: The data collected by E^nR (European Energy Network) concern the period 1994–1995 [37] and the types of data on R&TD are: Government expenditures expressed in ECU and national currencies, private expenditures and public and private expenditures. Furthermore, evaluation practices, technology aspects and foresight and effects of market factors on energy R&D are included. Four key aspects are examined: Evaluation and monitoring, technologies and foresight, driving factors in the energy markets and targets for EU intervention. Data provided for eight countries on private expenditure on energy R&D are incomplete [38].
- *PSI*: The data collected concerned the period 1990–1999 [39], were commissioned by a Research project (1998–2000). Responsible for information and data collection was the European Energy Network (E^nR). National and EU programmes and R&TD priorities are compared as well as expenditures and results, market developments, results of technology foresight studies and R&TD priority setting processes. Information on these fields is compiled in a prototype database. The PSI database is structured as follows (energy R&TD structure): (i) Energy R&TD expenditures in ECU (1999) and national currencies by groups of technologies and general energy technologies using IEA data and specified technologies in which the data compiled by national teams (ii) R&TD

actors sub-database (iii) R&TD support activities sub-database. In addition to this, the subdivision of RES technology categories in PSI database (governmental expenditures) concern the solar energy, wind energy, ocean, geothermal and hydro energy.
- *PNNL (Pacific Northwest National Laboratory)-BATTELLE project*: The data collected concerned the period 1999–2000 and were commissioned by Pacific Northwest National Laboratory operated by Battelle Memorial Institute for the US-DOE [40]. These data included expenditures on energy and RES R&TD, among which government and private expenditures percentages, analysis of trends in energy research, development and investment worldwide and crosscutting assessment of recent investments and reports on trends in energy R&D investment in the EU and eight countries (CAN, FRA, GER, ITA, JAP, NL, UK and USA). Information for private energy R&TD expenditures is available, but incomplete, since only few data are available for international comparison.

6.2. Definitions and comparisons

Research, development and demonstration can be classified according to the main steps of the innovation process that are described in the following:

- *Basic research*: Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.
- *Applied research*: Original investigation undertaken in order to acquire new knowledge. It is directed primarily towards a specific practical aim or objective.
- *Experimental development*: Systematic work, drawing on existing knowledge gained from research and/or practical experience, that is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.
- *Demonstration projects*: Projects that are of large-scale but which are not expected to operate on a commercial basis.

The most striking inconsistencies concerning the R&D expenditure data are summarised in the following paragraphs:

- *Government expenditures:* Recent data could only be found in the IEA database and the REDS database (the latter until 2001). Generally the IEA database represents a good basis for any data collection (in particular because it is continuously updated). However, as mentioned above, attention should be paid to the comments and values given by the REDS, the SENSER and the PSI project, since it seems that not all the IEA data were complete due to the lack of part of the funds given, especially from local governmental institutions. Another reason for the incompleteness of the IEA database is the lack of data concerning the institutional spending.
- *Private expenditures:* Data from the REDS project, the PNNL-Battelle project and the PSI/SENSER project are the only existing international data on this where some figures on private R&D expenditures are available. Most data on this issue are rather incomplete and do not cover all EU Countries and years. In practice, there are no complete international data concerning private expenditures.

7. Technology data

7.1. Review of methods

The present data gathering methods for RES technology data approaches are reviewed in this section. In particular, with respect to the broad set of existing literate, references of major relevance are discussed separately for the sectors of electricity (RES-E), heat (RES-H) and transport (RES-T).

- *Technology data for RES-E (& -CHP) (electricity and combined heat and power)*: A set of studies are available, which provide a comprehensive survey on RES-E technologies, thereby including detailed economic and technical data with respect to most common technologies. For biomass and biogas the technology data are available in EUBIONET [41]. For geothermal energy the common project of IEA and BMU [42] brings a lot of data. For hydropower a project with significant data can be found in Lorenzoni [43]. About solar systems at the Schaffer's project [44] a lot of technology data are available. In the case of photovoltaics, the alsema's project [45] seems to be very specific. For wind energy, significant projects such as the one of Greenpeace [46], of BMU [47] and individual papers such as the one of Neij et al. [48] and Beurskens and Noord [49] give a good picture about technology data for this kind of RES. Finally for tidal and wave energy good studies are of Thorpe [50], DTI/ETSU [51] and Michael [52] are available.
- *Technology data for RES-H*: In particular, the sources to be consulted for the techno-economic assessment of RES-H technologies are Kaltschmitt et al. [53], DLR/WI/ZSW/IWR/Forum [54] and BMU [47].
- *Technology data for RES-T*: For the techno-economic assessment in the area of biofuels, literature sources of major relevance are IEA [55], IPTS [56], CONCAWE [57], ECN [58]. Furthermore, a lot of individual papers exist in the international literature such as Henke et al. [59], Wyman [60] and Hamelinck [61].
- *Dynamic aspects—technological change*: Various studies have recently treated the aspects of technological learning with respect to energy technologies. In a general manner, covering a broad set of (RES) technologies, experience curves are discussed in BMU [62], a focus on photovoltaics is given in Alsema [45] and Schäffer et al. [44], whilst in case of wind energy (Neij et al. [48]) provides the most comprehensive recent survey. With respect to the future cost development of emerging new technologies like tidal and wave energy a stick to expert forecasts given by OXERA Environmental [63] seems preferable.

7.2. Definitions and comparisons

From a techno-economic point of view the following data categories appear to be of major relevance:

- *Production/technology data*: (i) Plant size (ii) lifetime (iii) efficiency (i.e. for conversion to electricity/heat/transport) (iv) fuel categories (v) full-load hours.
- *Economic data*: (i) Investment cost (ii) operation and maintenance cost (iii) fuel cost and (iv) generation costs.

Most striking inconsistencies appear in the context of economic data. More precisely, the dynamic context of expressed data is often not depicted in clear manner in literature, i.e., as e.g. investment cost change over time (due to technological change) it is of crucial importance to which date the values refer and, additionally, if they are expressed in nominal or real currency. With special regard to generation costs two other issues become important:

- The geographical coverage of expressed data—i.e. as resource conditions in case of wind or solar energy change largely among European countries the regional context of depicted values is of striking importance.
- Applied assumptions with regard to payback time and interest rate.

In order to give a better illustration of both issues addressed above, the current electricity generation costs of various RES-E options are illustrated in the following example. Their calculation is based on the economic and technical specifications, representing the broad range of resource-specific conditions among EU-15 countries. For the calculation of the capital recovery factor two different settings are applied with respect to the payback time: On the one hand, a default setting, i.e. a payback time of 15 years, is used for all RES-E options, and on the other hand, the payback is set equal to the technology-specific life time. The broad range of costs for several RES-E represents, on the one hand, resource-specific conditions as relevant, e.g., in the case of photovoltaics or wind energy, which appear between and also within countries. On the other hand, costs also depend on the technological options available—compare e.g. co-firing and small-scale CHP plants for biomass.

8. Conclusions

Indeed, there is already much information about energy issues available from many sources from organisations that intend to influence decision-makers in their choices. Particularly, the European Community has been proactive in seizing opportunities to develop new renewable energy technologies and building-up leading industries. Based on the current analysis, a number of data providers exist:

- International data providers, such as the European Commission (notably DG RTD, DG TREN, DG JRC, EUROSTAT), the IEA and the UNECE;
- RES association, such as the EWEA, the AEBIOM, the EPIA, the ESIF and others;
- A number of projects, such as the ODYSSEE Energy Efficiency Indicator Project and the EurObserv'ER Project (tool for monitoring the different RES).

However, validated data offer opportunities to analyse and understand the reasons that drive to the variations occurring over time in the activities considered. Strong and sound data provide the foundation for policy and market analysis, which in turn will better inform the policy decision process, helping thus policy makers to:

- Select the right policy and policy instruments best suited to meet domestic and/or international policy objectives or;

- Make the required adjustments to an existing-policies or policy instruments that failed the market.

In particular, the following observations are made for each one of the required RES data categories:

- *Techno-physical data*: There have been identified two best available methodological approaches for the collection of techno-physical data. The first of them is the Annual Renewables and Waste Questionnaire (UNECE), the IEA and the EUROSTAT. The second approach is a 2001 edition EUROSTAT study supported aimed at development of statistics on EU RES, where emphasis was put on a data collection methodology. Most important improvements are necessary at the level of the availability and quality of the base data, which are necessary to calculate indicators. In addition to this, the observed trend to prefer internationally compiled indicators to national indicators enhances the international comparability of the indicators.
- *Potential*: An important problem is to use the right definition of potential in the right context. In addition to this, it is difficult to identify disaggregated data on RES potential for RES electricity, heat and transport, taking also into consideration the dynamic character of RES potentials, which depends on technological progress and present penetration level. In this context, the suggested methodology for the assessment of country-specific potentials varies significantly from one RES category to another, between 'top-down' (e.g. for wind energy, photovoltaics) and 'bottom-up' approach (e.g. for geothermal electricity). As regards hydropower, it is highly recommended to distinguish between the potential for new plants and the potential for upgrading or refurbishing the existing ones. For solar thermal electricity best practice is to consider this electricity generation option only for Southern European countries (i.e. Greece, Spain, Portugal and Italy). For tidal stream and wave energy, if available, the potential assessment should be based on local studies or data, respectively. For wind farms, either offshore or onshore, in accordance to data regarding land use, overall area-potentials should be initially assessed and then wind maps have to be applied to the identified areas, characterised by certain 'wind characteristics'. For PV installations in principle, and building integrated PV, the best available technique for the calculation of the electricity generation potential is by linking the average figures of solar-architecturally suitable area per capita to country-specific features (mainly population size and annual solar irradiation).
- *Socio-economic data*: Socio-economic impact of renewable energy is of crucial importance. As regards the results of the employment impact of RES implementation, as best available practice can be considered the studies of the University of California-Berkeley, the Wind Energy—Facts, Industry & Employment and the final report of the Renewable Energy Sector in the EU. However, the availability of all necessary socio-economic (VA of industry, turnover of RES industry by sector) data is limited. For the data gathering on the level of RES technology production and energy plants using RES, data from the national (and local) economic, commercial, trade and handicraft chambers, national agencies for regional development and associations need to be collected.
- *R&D expenditures*: As foundation of the data collection on R&D expenditures should be considered the IEA database, which should then be checked with regards to the

crucial comments from the relevant projects (REDS, SENSER, PSI). Government expenditures can only be found in the IEA database and the REDS database (the latter until 2001). Since very often the data on private R&D expenditures do not exist on a country/technology/company level, a useful approach is to assess the number of scientists and engineers working in a specific sector and to conclude the financial spending from this figure. In addition to this, specific data categories, such as regional and institutional funding need special attention.

- *RES technology data*: In general, there is no homogenous database available for all RES technology data. Therefore, the wide range of possible data sources requires an accurate documentation of definitions, discrepancies and information missing at a sectoral level, e.g., done by energy system models. A number of models that include a wealth of RES technology data and should be a solid basis for reference purposes are the Green-X and the Invert and Admire Rebus. Generally these models draw from rather similar primary data sources, but provide—according to modelling requirements—a well-structured technology description.

The above considerations were put on a sound and publicly available discussion during a recent workshop, organised in the context of the SRS NET and EEE project under the umbrella of the IEA (France, Paris, 30 June 2006). In particular, the presented recommendations were commented from the high level relative stakeholders so as to be realistic and consistent. Finally, it was suggested that these recommendations could be an appendix to the IEA statistics manual.

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