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ASSESSMENT METHODS OF USING RENEWABLE ENERGIES

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ABSTRACT: *Human economic activities, irrespective of their type, being industrial, agricultural, commercial or touristic ones, have the goal to support the increase of human beings quality of life. Beside positive direct and desired effects of diverse human economic activities these could also have sometimes negative, undesired and even unthinkable impacts on environment and society. Especially activities related to energy generation can have several inadvertent unwanted impacts on environment and society. With the goal of assuring the sustainability of our human society it is therefore implicitly required to assess not only industrial processes but also especially energy generation activities by applying economic and technological methods of approach as well as environmental and social ones. In the context of global debates related to limited availability of fossil fuels, current activities concerning electrical and thermal energy generation are focused on using renewable energy resources on a global level for assuring corresponding energy needed by the population. During the last decades, assessment methods for evaluating using odds of renewable energy resources have been applied especially in the context of the pretty new discipline called Technology Assessment. Moreover, even new integrative assessment methods have been developed for simultaneously considering interdisciplinary aspects in assessing procedures. Technology Assessment has been firstly designed in the United States and then it became well known in Western Europe as well, currently its specific assessment methods being fairly used on a worldwide level. In order to carry out environmental assessment studies of using renewable energy resources the pretty known tool of Life Cycle Assessment, LCA can be applied and successfully used. In the present article, general notions regarding assessment methods especially environmental ones will be considered. As an example a Fuzzy-Logic based integrative assessment method will be presented, where possibilities for assessing the regional use of renewable energy resources will be debated, after presenting the working way of Fuzzy Logic.*

Keywords: *renewable energy resources; assessment methods; environmental impact assessment; Fuzzy Logic; energy generation; life cycle assessment*;

1. Introduction

About half-century before the world started to understand in a holistic way potential impacts of human activities, especially of industrial ones. After the release of the first report to the Club of Rome, "The Limits to Growth" in 1972 [6] and after taking place, in the same year, the Conference for Environment in Stockholm, the mankind has finally started to understand that besides wanted effects of technological progress, undesired effects can appear. As a consequence the environmental awareness in the Western world began to change [5]. Created regional and global problems in environmental field started to be recognised as being stringent and implicitly as needing to be debated and in the end solved.

The issue regarding availability of different energy resources on a global level is nowadays a very discussed topic on scientific and technical level, as well as on socio-political one [3]. Renewable energy resources represent a source of unpolluting and inexhaustible energy. Due to their diversity and potential to be used anywhere on the planet, where they are available, their use continues to increase, transforming them in a competitive energy resource from an economic and environmental point of view.

As a member of the European Union, Romania has assumed a number of aims, one of them being the share of renewable energy resources in electricity production, what should be of about 38% in the year 2020 [7]. This means that national and regional strategies of using renewable energy resources are required to be established by respecting general aims on European level. In this way, certain regions will become sustainable regions, at least from the point of view of covering the increasing energy demand without supplementary negative environmental impact.

For assessing on regional level potential environmental impacts because of implementing certain renewable energy strategies, several assessment methods by certain calculation procedures have to be applied [4]. Assessment methods in this field are tools and instruments for collecting information to determine the extent to which certain energy strategies demonstrate desired outcomes for assuring sustainability. Several methods should be used to assess respective outcome, the assessment becoming pretty difficult when several interdisciplinary assessment criteria have to be coonsidered, some of them coming from environmental and social field and being hardly quantifiable [8].

In order to optimise technological applications from different points of view the discipline called *Technology Assessment* is to be used [9]. Technology Assessment has been firstly defined and used in the United States. Thereafter it became well known in Western Europe as well, especially when evaluating new innovative technologies in energy supply or mobility field. The discipline is basing on several instruments and methods to carry out technology assessment studies. Currently its specific assessment methods are used on a worldwide level. From the universe of methods and instruments there are some used to carry out environmental assessments of indus-trial activities, the most discussed one on international level being the *life cycle assessment, LCA.*

With regard to environmental assessments when using and applying technology assessment studies by life cycle assessment one pretty used procedure is represented by establishing the specific *environmental footprint*. In this way can be assessed which energy strategy based on which energy resources is representing a sustainable future energy strategy [7].

The established way of the environmental footprint of using different renewable energies, especially for photovoltaic panel systems, has as a base the determination of the corresponding CO2 emissions [6, 7]. By using the established environmental footprint, the time period can be calculated so that a photovoltaic panel system would have to operate, in order to neutralize possible pollutants emissions that would occur, if electricity would be produced by using fossil fuels. After this time period, the photovoltaic panel system becomes a sustainable energy resource. Different possibilities of optimization are selected by appropriate measures that can support the decrease of the environmental footprint of photovoltaic panel systems [7].

New technological developments but societal as well have brought the need for new comprehensive evaluations by using new integrative assessment methods. These have been developed for simultaneously considering interdisciplinary aspects in assessing procedures. As an example, *Fuzzy-Logic based assessment methods* will be presented, having as a base different Fuzzy Logic based methods developed for environmental field [9]. In this example possibilities for assessing the regional usage odds of renewable energy resources will follow.

In order to optimize different technological applications it is necessary to define clearly the rating perspectives of the approached technologies. In order to carry out a holistic comprehensive rating, the environmental perspective has to be considered as well, beside technical and economic points of view. Following this constraining conclusion it is necessary to carefully analyse and evaluate environmental impacts of technological applications, especially of energy supply based on renewable energy resources.

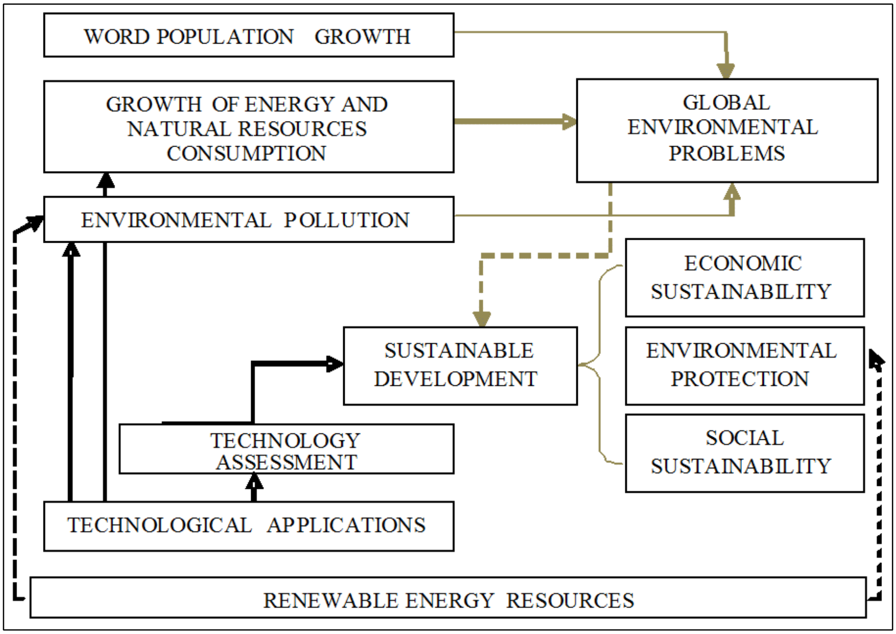

Fig. 1. Technological applications for assuring sustainable development

2. Renewable Energies for Getting Sustainability

As presented before, starting with the ‘70s, the world began to realize that beside positive wanted effects of human activities, these usually can hide some undesired effects and unthought dangers [5]. After this time the environmental awareness in the Western world began to change. It was clear that the arisen environmental problems have become very serious and needed to be solved. Nowadays we are confronting with a series of global problems, which can mainly be grouped in three parts:world population growth, growth of energy and natural resources consumption and envi-ronmental pollution, as presented in Figure 1 [5, 8].

In order to find solutions for the problems mentioned above, worldwide began discussions on scientific, economic and socio-political levels. It was clear that it was a need for a solution that should be applicable by regional differences to the developed as well as to the developing countries. The Brundtland Report of the World Council on Environment and Development, published in 1987, represented a result of these worldwide political discussions, actually defining for the first time the concept of *sustainable development* [2]. The defined concept has been worldwide accepted as being the potential solution for the global complex ecological, economic and social problems. The concept of sustainable development has been largely discussed during the Conference for Environment and Development in Rio de Janeiro 1992, known as ”Rio-Conference”, as well as in the closing document ”Agenda 21“ [3, 8]. Many actions after this time have emphasized that the development of technical, economic, social and environmental systems has to be analysed in synergetic relation.

Among such actions the follow-up conferences can be mentioned, ”Rio + 10” – Conference in 2002 in Johannesburg and ”Rio + 20” – Conference in 2012 again in Rio de Janeiro, as mentioned at the Sustai-nable Development Knowledge Platform [13]. In order to apply the concept of Sustainable Development there were needed more concrete strategies, but without neglecting the made progress during the years in this pretty complicated but sensible field [3, 6, 7].

This concept can be interpreted in many different ways, but at its core, it represents a development that is able to fulfill the growing demand of today’s people, by increasing their life quality, without compromising the ability of future generations to meet their own needs.

Concerning assuring sustainability on a global level a relevant question is connected to existing possibilities for assuring the energy demand of the population in a way that the environmental pollution is not increasing and the energy resources are available for the whole world population [3].

Operationalising sustainability can be got by applying one of the two strategic possibilities, which are mentioned in the following [9]:

- establishing goals on global level, measures to get these goals being prepared on global and national level and applied on regional or local level;
- establishing goals on regional level, measures being prepared on regional level and immediately applied; potential effects of these measures are to be evaluated on global level too.

First strategy is especially applied when carrying out studies in form of scenarios, for instance with the goal of finding future sustainable energy supply systems with minimal effects on the environment. Such a study called ”Global Energy Perspectives till 2050 and more” has been realized at the International Institute for Applied Systems Analysis, IIASA, in Laxenburg/ Vienna [14]. It bases on mathematical models to describe industrial and economic processes. With the help of a database simulations can be run and different scenarios gained. The goal is to find the right ways for the proposed aims and to help with concrete measures the decision making process on political level. On the other side applying renewable energy resources by using diverse technologies with the goal of getting Sustainable Development is a pretty debated current option on global level [1. 4].

Second strategy is illustrated by many actions in form of Local Agendas 21 led especially in Western-European countries after the Rio-Conference in 1992. On this point national scenario studies could be mentioned, which try to find sustainable ways for the future national development in global context, as for instance the Sustainable Development Knowledge Platform [13]. A general methodology to concretely apply sustainable development on a regional level is materialized in the following steps [8]:

- defining the sustainability problem;
- establishing space and time scales;
- systemic approach of the region by modelling the interactions;
- establishing concrete aims for the studied case;
- developing concepts and measures by establishing priorities;
- developing evaluation and control instruments;

- verifying potential results to be got after introducing proposed measures by carrying out simulations and developing diverse potential scenarios;
- applying in the practice the developed concept.

The operationalization is only possible when for a certain problem-case concrete aims are established and concepts to achieve them are developed. Sustainability has to be newly defined for each different case, where space and time scales are to be established for each case [9]. To make the concept of sustainability applyable on national or regional levels operational criteria are needed. Such criteria may request specific priorities, which are different from a region to another and may be controlled by using specific indicators known as sustainable development indicators [3, 9].

At this point should be stated that assuring the sustainability of our human society means developing and applying proper sustainable development strategies on different levels, i.e. on national, regional as well as on local level. Gaining strategies on local level means actually developing strategies for the urban sustainability in cities. The vision of having in the future *sustainable cities*, by taking into account regional differences, is worldwide a pretty discussed topic, also in some Eastern European countries [9]. It was recognised that *urban sustainability* is among the most critically important global issues of the 21st century. It is estimated that over 50% of the world's population now lives in urban areas. Some developed scenarios for the future urban development estimate that by 2050 the proportion of the global population living in cities the will rise to 70% [3]. The big challenge is that cities now consume about 75% of all the world's energy and emit around 80% of all greenhouse gases [13]. Therefore the fight against climate change will be won or lost in cities, so it is crucial that the urban habitats will become more efficient - not only for themselves, but for future generations and the earth's diverse ecosystems.

In this context more and more attention is paid to diverse odds of using renewable energy resources on different levels [1, 4]. It is well known that renewable energy is representing a source of inexhaustible energy, it is diverse and has the potential to be used anywhere on the planet [7]. With regard to the concept of sustainable development and to assuring the growing energy demand on a global level it is more than clear that renewable energy resources are representing the most appropriate way in this direction.

3. Technology Assessment, TA

By rating for instance environmental impacts of technological applications different development levels in technological field, as well as in economic and environmental fields, connected to the socio-political field in various countries have not rarely had as a result serious difficulties in applying the concept of Sustainable Development on a local level [9]. In order to operationalise the concept of sustainable development a general and flexible methodology by a systematic approach is necessary to be developed, which has to make possible applying Sustainable Development to each concrete case with the specific conditions. An important role in this context play concrete methods and instruments of Technology Assessment for assessing industrial processes from a holistic point of view regarding potential economic, environmental as well as social impacts [3, 9].

In the last time among scientists the concept of Technology Assessment (TA) has become pretty well known, there are a lot of publications which treat general notions, goals, methods and instruments with respect to this concept [9]. When going through the given methodology for Sustainable

Development one can recognize that many steps can be also identified in the phases distinguished in Technology Assessment [9]. Often a concrete sustainability problem is to be solved by carrying out a TA-study. Or a TA-study has as a goal to research if a technology has negative effects on different domains that mean if the effects of a technology application are not in conflict with Sustainable Development goals.

It is interesting to debate applying sustainable development on the level of an industrial process or on a product level. In this field the operationalisation of sustainable development means to use instruments of TA. Also many methods which are used in TA are the base for applying sustainable development. In Figure 1 Technology Assessment is mentioned in accordance to the methodology for sustainable development operationalisation [3, 9]. In order to verify possible impacts of proposed measures, control and evaluation instruments are needed, for shaping local or regional sustainable development. Operationalisation of sustainable development with technology assessment means analysing the stability of complex dynamic environmental, economic and social systems in order to discover developments which lead to instabilities. In this context there are many fields where research is needed; after [3] these fields are:

- State description by using Sustainable Development Indicators (SDI);
- Dealing with uncertain, unclear knowledge or non-existent knowledge;
- Improvement of methods and instruments;
- Orientation with values and considering value conflicts;
- Developing evaluation criteria;
- Modelling and simulation of dynamic systems.

The concept of Technology Assessment equally of how it is named, namely Technology Evaluation, Innovation Research, System Analysis or others, brings together almost all of the scientific disciplines with the question of how sustainability can be operationalised by using instruments of Technology Assessment, tools for rating environmental impacts of technological applications, such as:

- Environmental Impact Assessment;
- Eco-Audit;
- Life Cycle Assessment, LCA.

4. Life Cycle Assessment, LCA

The LCA as presented in the ISO 14000 family norms for Environmental management [12] is an analysis which registers all the effects on the environment of a product during its life, "from the cradle to the grave", from the production to the consumption and recycling. The general life cycle of a product is presented in Figure 2. It can be remarked that besides production and

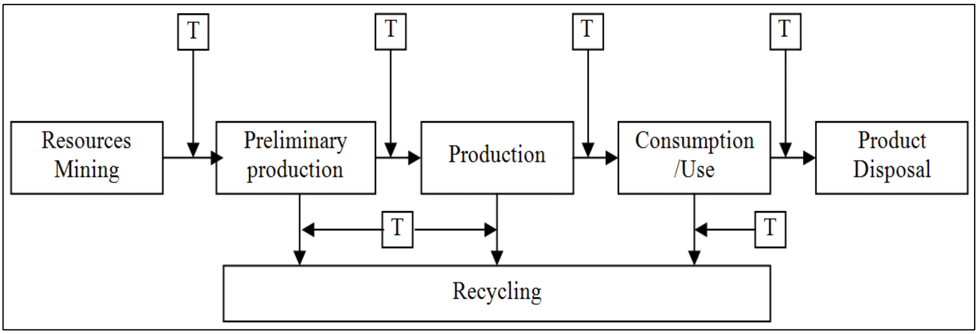

Fig. 2. General life-cycle of products

consumption processes also transport processes are taken into consideration. With T are indicated transport processes within the life cycle of a product.

Life cycle assessment is used to improve products production lines, to compare different products and to ecologically optimise life cycles of them. The LCA can be performed as a singular study or as a comparative study by registering material and energetic flows in the production processes. Such an analysis contains several steps [10]:

a) definition of goal and scope;
b) inventory analysis;
c) impact assessment;
d) results interpretation.

a) Definition of goal and scope - The goal shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated.

b) Inventory analysis - It involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system.

c) Impact assessment - It is aimed at evaluating the significance of potential environmental impacts using the results of the inventory analyses. The impact assessment may include elements as: assigning of inventory data to impact categories, modelling of the inventory data within impact categories and possibly aggregating the results in very specific cases and only meaningful.

d) Interpretation of results - in this phase the findings from the inventory analysis and the impact assessment are combined together. The interpretation may take the form of recommendations to decision-makers, consistent with the goal of the study.

5. Fuzzy Logic based Assessment Methods

Regarding this subject a great diversity of materials and books are available at present, which treat fuzzy logic more or less detailed [9, 11]. In the following a succint presentation of the important notions related to fuzzy logic will follow.

Fuzzy logic is based on the knowledge that reality is rather unexact than precise, because all afirmations have a certain free interpretation domain. Traditional binary logic is part of fuzzy logic as a special case operating only with two values of interpretation. In contrast to the well-defined sets of set theory, real existing sets are rather fuzzy limited, essentially due to the uncertainties in used language. A set is fuzzy limited if the assignment of one is not given to all members of the set, what is the total membership. A fuzzy set is defined by the generalized characteristic function, called the *membership function* μ. This real function can take on any values, but usually it is normalized into the interval [0, 1].

The key notion when modelling with Fuzzy Logic is the linguistic variable [11]. The mathematical description of processes requires a precise quantitative presentation of the influences considered. The usual strategy is to disaggregate complex entities into many variables connected by complex functional description. In opposition to this, verbal rules of behaviour contain fuzzy formulated knowledge, which is generally more intelligible. Beyond that, linguistically formulated variables contain more aggregated information content, and therefore it is more difficult to quantify them.

To process fuzzy formulated knowledge several linguistic variables must be linked by linguistic operators. The connecting rules represent the materialization of the knowledge about the analysed and modelled system that is stored in a rulebase or knowledge base, similar to expert systems [8, 11]. The procedure consists of the following steps: fuzzification, inference and defuzzification, as presented in Figure 3.

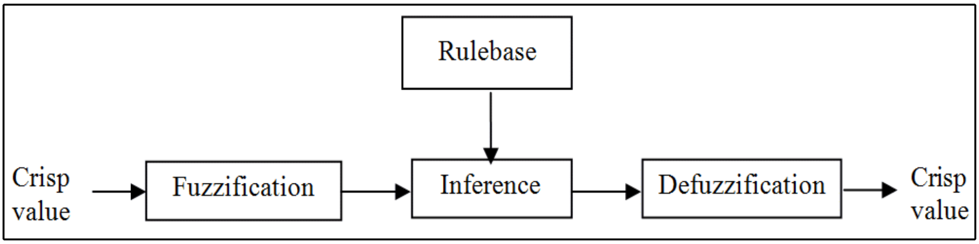

Fig. 3. General operational diagram by Fuzzy Logic applications (after [8])

The concept of linguistic variables connects the description of verbal and therefore fuzzy information with mathematical precision. The values of a linguistic variable are verbal expressions, called *linguistic terms*, for instance *small*, *medium* and *high*, as given in Figure 4.

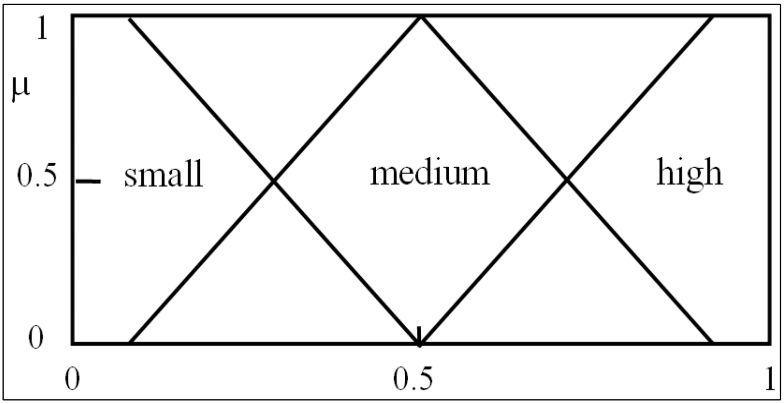

Fig. 4. Linguistic terms and membership function for usually used linguistic variables applied for various Fuzzy Logic based models [11]

The content of each linguistic term is identified with one fuzzy set and assigned to the related numerical scale of the basic variable by a particular membership function. Thus, the fuzzy sets build the connection between linguistic expression and numerical information [11].

The fuzzification step is the linguistic interpretation of any crisp input value of a basic variable. This means, in the step of fuzzification follows the determination of the membership values of each crisp input to all linguistic terms, as shown in Figure 4. For this purpose, the basic numerical interval, the number of the linguistic terms and the according verbal expressions of the linguistic variable have to be previously fixed in accordance to be complexity of the analysed system and the desired sensitivity of the shaped *fuzzy model* [8, 11]. The quantitative transformation of the verbal expressions is sensitive, especially to the shape of the membership function.

Due to computing efficiency often triangular and trapeziform membership functions are used, but any other distribution function is also possible. In figure 4 a fuzzification example is presented, which is actually used for gaining the linguistic terms needed for defining usually applied fuzzy variables [8, 11].

After fuzzification, the inference has to draw conclusions from the propositions with regard to the knowledge base. The knowledge formulated as IF-THEN-rules has to be applied to the new fuzzy statements. Inference consisting of aggregation of the IF-parts of each rule, implication and accumulation of the results of the rules THEN-parts, causes a weighting of each single rule on the total result. The aggregation of the left side is only necessary when more than one proposition impacts an implication. This could be obtained by appropriate intersection operators (t-norms). The result of the implication itself is the assignment of a proposition of a rule to a linguistic term of the output variable. Running all rules generates several different images of the output variable because of the different parts of the output linguistic terms. These have to be accumulated to a single conclusion by a union operator (t-conorm) because of the alternative character of the rules. This result consists of different participating linguistic terms of the linguistic output variable.

A crisp output value can be drawn from the resulting membership distribution by several procedures. The most familiar one is to determine the center of gravity of the area representing the resulting membership distribution of the participating linguistic terms. The abscissa value represents then the crisp output value.

Such a knowledge based approach means the methodical attempt to substitute missing or inefficient algorithmic procedures by using human knowledge. Thus, even partially fulfilled conditions result in partially fulfilled conclusions, so these conditions are considered also in the result. Therefore, the possibility to consider uncertain information in systems modelling is given, fact that encourages applications in the field of environmental systems and of using renewable energy resources.

In order to minimize these deficiencies methods of soft-computing have to be used [8, 11]. Especially Fuzzy Logic offers possibilities for defining indicators and assessing using potetnial of renewable energy resources by its potential to integrate complexity in the systematic and exact mathematical approach [11].

Such a Fuzzy Logic based integrative assessment method applied for using renewable energies contains several assessment criteria from economic, environmental and social field as well, as presented in Figure 5 and it can be used for decisions regarding future using potential of renewable energies on regional level [1].

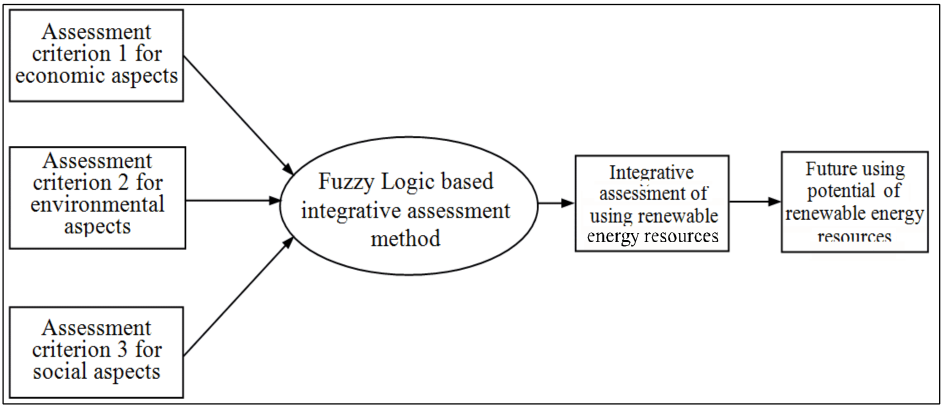

Fig. 5. Flow chart of Fuzzy Logic based assessment methods of using renewable energy resources

6. Conclusions

The heightened awareness for the possible impacts on environment associated with energy resources, especially renewable ones has increased the interest in the development of methods and instruments of Technology Assessment. Industrial activities have the direct goal to help increasing the population quality of life. Beside positive direct and desired impacts of industrial activities these can have also negative, undesired and sometimes unthinkable effects on the environment and society. There are several tools of Technology Assessment for evaluating impacts of human activities. The Life Cycle Assessment, LCA is presently world wide used to assess environmental impacts of products and energy resources, but the evaluation question is still not definitively clarified. An evaluation method based on establishing the environmental footprint is presented, in this case of using different renewable energies by establishing the corresponding CO_2 emissions.

Results emphasize the working way of the presented method and allow an evaluation of different phases in the life-cycle of energy resources. The idea is to reduce as much as possible the environmental impact of each phase in the general life-cycle of the analysed energy resources.

The one related to obtaining the needed basic materials causes a certain environmental impact, but the phase of product utilization generally causes a higher environmental impact than the production itself. It seems that actually the field of changing human mentalities regarding products or resources using ways is much more complicated than obtaining a less pollutant process and this aspect often overruns the technical competencies of the engineers. From this reason in the future there is a need for inter- and transdisciplinary cooperation for optimizing the life cycle of energy resources and their environmental impacts by minimizing their environmental footprint. The Fuzzy Logic based method offers new possibilities by its potential to integrate complexity in the systematic and exact mathematical approach and assures a transparent assessment. The Fuzzy Logic based integrative assessment method presented in this article for renewable energy resources shows the manifold and important possibilities of Fuzzy Logic based methods to solve environmental problems and to operationalize the concept of sustainable development on regional level.

References

[1] Afgan, N., H., da Graça Carvalho, M. (Eds.) (2018), *New and Renewable Technologies for Sustainable Development*, Springer Nature, Switzerland.

[2] Hauff, V. (Ed) (1987), *Our Common Future*. The Brundtland Report of the World Commission on Environment and Development, Oxford Univ. Press, Oxford

[3] Jischa, M. F. (2014), *Herausforderung Zukunft*. SpringerSpektrum, New Edition, Berlin/Heidelberg

[4] Kaltschmitt, M. S. (2014), *Erneuerbare Energien - Systemtechnik, Wirtschaftlichkeit, Umweltaspekte*. Springer, Berlin.

[5] Meadows, D. and D. (1972), *The Limits to Growth*. Universe Book, New York.

[6] Oancea, A., Tulbure, I. (2017), *Environmental Footprint of Using Renewable Energies*. ECOTERRA - Journal of Environmental Research and Protection, 33 - 39.

[7] Oancea, A. (2018), *Optimization Possibilities of the Environmental Footprint of Renewable Resources*. Alba Iulia: Master Thesis - "1 Decembrie 1918" University of Alba Iulia.

[8] Tulbure, I. (2003), *Integrative Modellierung zur Beschreibung von Transformationsprozessen*. Teza de abilitare. Universitatea Tehnica Clausthal. Germania. VDI-Fortschrittsberichte, Reihe 16, Nr. 154, VDI-Verlag, Düsseldorf, Germany.
[9] Tulbure, I. (2013), *Technikbewertung. (Technology Assessment)* - Lecture Notes. Clausthal University of Technology. Clausthal-Zellerfeld, Germany.
[10] VDI-Richtlinie 3780 (2000), *Technikbewertung - Begriffe und Grundlagen (Technology Assessment – concepts and basic notions)*, new edition, Düsseldorf, Germany.
[11] Zimmermann, H.-J. (1993), *Fuzzy Technologien*. VDI-Verlag, Düsseldorf, Germany.
[12] ISO Central Secretariat, 2009: *ISO 14000 family - Environmental management*. International Organization for Standardization, Genève, Switzerland, https://www.iso.org/iso-14001-environmental-management.html http://www.iso.org/iso/theiso14000family_2009.pdf
[13] *Sustainable Development Knowledge Platform*, https://sustainabledevelopment.un.org
[14] International Institute for Applied Systems Analysis, IIASA, *Global Energy Perspectives till 2050 and more*. Laxenburg/Vienna, http://pure.iiasa.ac.at/id/eprint/5445