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ABSTRACT

DOCTORAL THESIS

CAPITALIZATION OF THERMAL POWER FROM SECONDARY ENERGY SOURCES – PART OF THE STRATEGY FOR THE SUSTAINABLE DEVELOPMENT OF THE POWER SYSTEM IN THE JIU VALLEY

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1. Research topic. Topicality, necessity, importance

The 17 OSD (objectives of sustainable development) include four essential objectives for turning the notion of sustainable development operational; these objectives regard energy, environment and society.

The ***topicality*** of this thesis is given by the fact that, owing to its content, it approaches aspects of the four objectives:

- Objective 7, which regards accessible energy, the safety of energy providing and the sustainability and efficiency of energy systems, is attained through the large-scale capitalizing of energy renewable sources and secondary energy sources, the significant decrease of generating greenhouse gases, correlated with the change in approaching energy management and the patterns of energy consumption;
- The carrying out of Objective 9 implies the implementation of a competitive and sustainable industrialization, under the circumstances of strengthening circular economy and increasing the share of renewable energy;
- The goal of Objective 11 requires the modernizing and performance increase for the energy and environment elements that are part of the concept of intelligent and sustainable towns;
- Objective 13 manifests itself through promoting a series of capitalizing solutions for the RES specific for the area – thermal energy from energy stations, natural gas from degassing facilities within mining units, biogas produced through processing household waste and wood biomass from waste coming from wood industry.

The thesis is based on carrying out the major goal targeting the operationalization of the concept of sustainable industrial development, which regards the maximizing of useful effects in the context of minimizing resources consumption, and is achieved through:

- Decreasing and capitalizing waste that represents an important part of circular economy;
- Decarbonizing energy processes;
- Reducing GHG (green-house gas) emissions;
- Promoting renewable energy resources.

The ***importance*** of the thesis is emphasized by two aspects:

- It addresses certain elements of energy transition;
- While considering the above clarifications and adapting them to the present condition of the community energy system in the Jiu Valley, the doctoral thesis, through its topic and content, targets the proposal and analysis of feasible solutions for ranging the system explored within the concept of sustainable energy exploitation.

2. Objectives of doctoral research

The **general objective (GO)** of the doctoral thesis is the theoretical and experimental foundation of a series of solutions that are able to respond the challenges community capital in the Jiu Valley has to face.

The main challenges regard:

- Finding local solutions capable to diminish the effects of coal mines termination and extinction of related industrial activities;
- Analyzing a series of variants for invigorating community energy system;
- Efficiently capitalizing primary and secondary energy resources available in the area;
- Protecting and improving the quality of natural capital together with improving the conditions for human and social capital.

The doctoral thesis focuses on capitalizing thermal energy from secondary resources, which is a part of the sustainable development of the energy system of the Jiu Valley.

With a view to suggest a series of variants able to respond the previously mentioned challenges, the doctoral thesis includes the following specific objectives **(SO)**:

- **SO 1.** Carrying out a documentary synthesis regarding the capitalizing of secondary energy resources (SER), while highlighting the solutions that are feasible and efficient for the Jiu Valley;
- **SO 2.** Displaying the main goals of sustainable power industry with a view to checking and motivating the ranking of the measures proposed within the concept of efficient, competitive and innovative power industry;
- **SO 3.** Exploring descriptively and analytically the opportunity for employing cogeneration in order to efficiently capitalize the available secondary energy resources in the Jiu Valley.

3. Structure of doctoral thesis

The thesis includes: an introduction, six chapters, a table of contents and bibliography, displayed in 100 pages, 18 tables, 47 figures and 114 bibliographic references.

Chapter 1, called CURRENT STATE REGARDING THE CAPITALIZING OF THERMIC ENERGY FROM SECONDARY ENERGY RESOURCES, synthetically presents the following: the international context that concerns energy resources and their capitalization; the scenarios addressing the evolution of global energy demand and offer; the position of biomass within the sustainable energy transition; the criteria required by the sustainability of energy transition; the definition, origin and importance of employing secondary energy resources; biomass – a resource for thermic/electric/refrigerating energy; biomass – a biogas resources; bio-fuels – biomass for car transportation; biomass – raw material for chemical industry, and waste incineration – a secondary energy resource. The SER options displayed take into account the existence and potential of these resources in the Jiu Valley.

Chapter 2, which deals with SUSTAINABLE POWER INDUSTRY – CONCEPTS AND SPECIFIC NOTIONS, includes a documentary synthesis that regards the following aspects: importance and motivation of approaching sustainable power industry – objectives; the relation between environment and power industry; specific types of approaching (structural, historical, systemic); fundamental elements focusing on sustainable development; principles of sustainable development; objectives of sustainable development.

With a view to supporting the implementation of a modern solution for improving the use of energy resources, **Chapter 3,** called COGENERATION – AN EFFICIENT METHOD FOR CAPITALIZING SECONDARY ENERGY RESOURCES – OVERVIEW REGARDING COGENERATION, focuses on: the principle of cogeneration, the advantages and disadvantages of cogeneration, types of cogeneration systems, arguments in favor of tri-generation, graphic quantification of a variant of efficiently capitalizing combustible waste, comparative performance of generating sets through cogeneration.

The content of **Chapter 4**, which regards the VARIANTS FOR THERMIC CAPITALIZATION OF SECONDARY ENERGY RESOURCES IN THE JIU VALLEY, focuses on the assessment of the energy potential of the secondary energy resources available in the Jiu Valley and the options for capitalization, while approaching the following topics: energy assessment of biomass and capitalization solutions, energy assessment of the biogas originating in

waste water/urban waste treatment plants and capitalization solutions; use of Stirling engines and heat accumulators with heat pipes for natural gas recovery installations coming from degassing coal layers, energy performance elements for SER biomass, comparative analysis, based on the assessment of the life cycle of energy (LCEn), of the performance of coal TEPSs and biomass waste TEPSs.

In order to support theoretically and practically the opportunities for the energy capitalization of a series of options of SER, available in the Jiu Valley and displaying an economic potential, while also energy efficient and environmentally favorable, I elaborated a series of case studies whose performance, experimentally determined and calculated, are shown in **Chapter 5**, which regards the THEORETICAL AND APPLICATIVE FOUNDATION OF COGENERATION EFFICIENCY IN RELATION WITH THE CAPITALIZATION OF SECONDARY ENERGY RESOURCES IN THE JIU VALLEY. These case studies are as follows: real thermal energy assessment, schedule of steam bio-generation at a lumber factory; use of wood waste for providing thermal energy to the heating system of a group of dwelling places; energy analysis of a waste water treatment plant; option for capitalizing the gas from the degassing system of a coal unit; capitalization of secondary energy resources – thermal energy. The case studies displayed, exhibiting a capitalization potential in the Jiu Valley, show the following aspects that might contribute to the economic and social recovery of the Jiu Valley:
- Existence of efficient and feasible options for replacing coal and adapting the energy equipment relying on coal for capitalizing secondary energy resources, including the capitalization of biomass resources from forestry and agriculture;
- Upgrading the systems of urban thermal heating (some of these systems have been recently modernized) and promoting cogeneration / tri-generation, in the context of the existence of certain potential beneficiaries;
- In the case of the mining units still active, it is recommended that they increase and modernize degassing installations which might be fitted with equipment for gas recovery – Stirling engines and heat accumulators;
- Proposal of a solution for capitalizing stockpiles through re-vegetation with energy plants rapidly growing and displaying a high caloric power, a renewable resource that might be used in all the cases presented in this chapter.

Chapter 6 displays the general conclusions, the personal theoretical and practical contributions, future opportunities and perspectives, including present-day performance, solutions for increasing performance, and the future options for providing the sustainability of the evolution of the community system in the Jiu Valley. Chapter 6 ends with the exposure of the research boundaries.

New issues the work deals with:
- Systematization and synthesis of a series of aspects required for the operationalization of the concept of sustainable development;
- Comparative presentation of the performance of cogeneration systems;
- Quantification and graphic presentation of the advantage of capitalizing fuel’s potential through tri-generation;

- Comparing the indicators for energy and exergetic performance for electro-energy cogeneration groups, presented by two different companies;
- Analysis of the opportunity for using Stirling engines and heat accumulators with heat tubes for the installations that capitalize natural gas originating in coal layers degassing;
- Graphic presentation (relying on documentary sources) of a series of elements of energy performance for SER biomass;
- Comparative analysis, relying on energy life cycle (LCEn), of the performance of coal TEPSs and biomass waste TEPSs;
- Presentation of a series of case studies carried out while relying on *in situ* determinations.

4. Degree of complexity and novelty of research

The ***degree of complexity*** is displayed by the approaching and solving of the topic and its objectives, while employing analytical models and practical applications for validating the solutions proposed. In the case of the analytical instrument and applicative case studies, knowledge belonging to multi-disciplinary and interdisciplinary domains has been addressed (physics, mathematics, data processing based on calculation algorithms, thermal energy, environment engineering and management, elements of sustainable development and energy transition).

The ***degree of novelty*** of the work is emphasized by the manner of supporting a series of new solutions for the operationalization of the notion of sustainable power industry in the Jiu Valley. The case studies, based on *in situ* determinations, include new elements for the argumentation of the solutions proposed.

5. Personal contributions

5.1. ***Formulating general conclusions*** based on documentation and the analyses carried out:

With a view to respond the present-day requirements that regard sustainability, the capitalization of secondary energy resources is feasible on grounds of its availability in the Jiu Valley. It might contribute to the evolution of the community energy system in accordance with the postulates of sustainable development: economic efficacy, ecological responsibility and social solidarity.

The options displayed that regard the secondary energy resources are determined by the existence and potential of the recoverable energy of these resources in the Jiu Valley.

When approaching the notion of sustainable power industry we should consider the fact that, from a structural perspective, the development of human society is determined by the triad: economic – social – ecologic. Each of these factors design a system, which simultaneously evolve: internally (their own elements and laws, pre-existence of a series of assumptions, specific resources and forces, characteristic effects, their own self-regulation mechanisms) and externally (interaction with the other two systems through mutual fluxes of energy, substance and information). Within this group, the systems, especially those that are far from being balanced (socially and economically) export their inefficiency to the less developed systems or to the future. The utility functions of each system regard the following:

- The ecological system → preservation of bio-diversity and self-regulation mechanism;
- The social system → providing a high level of welfare for all the members of the society;
- The economic system → maximizing economic efficiency in the context of minimizing natural resources.

The energy analysis of a community system should target the identification of the means of interference among the three systems as well as the highlighting of the measures required for

preserving a dynamic balance both at the level of the macro-system and at the level of each of the three component systems.

The main circuits of the energy fluxes in society include three components: extraction-use-drop off. While watching the fluxes conveyed within the three components – extraction, use and drop off – we are able to see a very important fact: in the case when in the area of extraction and use, fluxes are totally controlled, in the area of drop off, this happens only in certain cases and, most often, only partly.

Considering the components, the fluxes and the actions within the combination society – nature, we notice that the development of society is determined by two factors:

- The limited amount of mineral resources;
- The limited capacity of nature for assimilating waste.

Most of the time, it is not the amount of the mineral resources that limit development, but the capacity of ecosphere to assimilate waste.

The sustainable evolution of a community energy system should determine the achievement of the following objectives:

- The regular decrease of mineral resources dependence, such as fossil fuels or uranium;
- The regular decrease of non-degradable substances production, which do not exist in nature;
- The regular decrease of depending on those activities that limit the productive areas of the ecosphere, for instance, the use of very long route transportation;
- The efficient capitalization of available energy;
- The implementation of a more economically efficient, ecologically responsible and socially beneficial manner to produce services that increase human value.

The topic this work deals with regards the preoccupations for providing the sustainability of the community energy system, in the context of observing the postulates of sustainable development (economic efficiency, ecological responsibility, social solidarity), while targeting the maximizing of welfare correlated with minimizing resources consumption and preserving environment quality.

When proposing the solution for capitalizing biomass, I also considered the experience of the Jiu Valley area in capitalizing with high efficiency energy resources, while using cogeneration.

With a view to motivate and convince the decisional factors to accept the implementation of the option proposed, I emphasized the main advantages of cogeneration:

- Energy advantages of cogeneration;
- Advantages of cogeneration in the field of preserving the quality of the environment;
- Economic advantages of cogeneration;
- Social advantages of cogeneration.

The quantity and quality performance might be considerably increased when using tri-generation, given that the area under analysis and the neighboring regions own an agricultural and livestock sector capable of providing a consolidated system for storing and cold preservation of food.

The disadvantages specific for the various types of installations are nonetheless outweighed by SER capitalization and might be significantly decreased through flattening yearly load curves.

With a view to provide a means of distinguishing, based on energy performance, among the offers for generating sets with cogeneration, I have carried out a comparative analysis of performance indicators for two types of generating sets with cogeneration. I also calculated the performance indicators relying on the data included in the leaflets of the building companies. The result of these calculations had in view energy and economic performance, enabling beneficiaries to choose the optimal variant.

The evaluation of the energy potential of the SER available in the Jiu Valley and the capitalization options give well-reasoned suggestions for the activities required to increase the sustainability of the community energy system in the Jiu Valley.

At the level of the Jiu Valley, biogas production might be increased through modernizing treatment plants and capitalizing the resources belonging to the mountain livestock and agriculture specific to this area.

The capitalization of the gas generated by degassing the coal deposits belonging to the mines under exploitation sensibly increases the energy potential of the area.

The statistics taken from specialized works, processed and graphically displayed in this work are able to motivate the objective of the topic I chose though emphasizing energy, economic and ecological advantages of the options proposed for capitalizing the existing SER in the Jiu Valley.

The comparative analysis, based on the life cycle of energy (LCEn), on the performance of coal TEPSs and biomass waste TEPSs, quantitatively and qualitatively set forth the advantages of biomass:

- The flux related to conventional fuel is 58.57 % higher than that of biomass;
- The total energy cost for biomass is 50.61 % lower than that associated with conventional fuels;
- The ratio fuel energy cost / total energy cost for biomass is 16.12 % lower than that related to conventional fuel;
- The ratio energy provided / total energy cost for biomass is 102.51 % higher than the one associated with conventional fuels;
- The ratio net energy / total energy cost for biomass is 102. 46 % higher than the one related to conventional fuels.

The case studies displayed, which might be capitalized in the Jiu Valley, show the following aspects that might contribute to the economic and social revival of the Jiu Valley:

- Existence of a series of efficient and feasible energy options to replace coal and adapt coal energy equipment with a view to capitalize SER, including the capitalization of biomass resources from forestry and agriculture;
- Reinstating urban thermal systems (some of them being recently modernized) and promoting cogeneration / tri-generation in the context of a series of potential beneficiaries;
- Mining units still in activity should increase and modernize degassing equipment completed with equipment for using gas – Stirling engines and heat accumulators;
- Proposal of a solution for capitalizing stockpiles through re-vegetation with energy plants rapidly growing and displaying a high caloric power, a renewable resource that might be used in all the cases presented;
- A feasible option for capitalizing the surface of stockpiles consists in locating photovoltaic panels in the context of a spectacular increase of solar radiation conversion efficiency;
- Depending on technology improvement for 2030÷2050, installing tanks that contain energy micro-algae on stockpiles might be a feasible and efficient solution.

5.2. Personal theoretical contributions:

- Carrying out a documentary synthesis that regards the capitalizing of SER, while setting forth feasible and efficient solutions for the Jiu valley;
- Displaying the main goals of sustainable power industry with a view to checking and motivating the framing of the measures proposed within the concept of efficient, competitive and innovative power industry;
- Descriptive and analytic exploration of the opportunity for using cogeneration in order to efficiently capitalizing the SER available in the Jiu Valley;
- Proposing a series of achievable options for the thermal capitalization of secondary energy resources in the Jiu Valley;
- As biomass is the most important renewable resource in the Jiu Valley, I made a presentation of biomass use options (including biomass waste);

- With a view to fitting in the concept of sustainability the present preoccupations for energy efficiency, I selected the operationalization criteria of sustainable development for the community energy system in the Jiu Valley;

- The approach of the Jiu Valley's community capital through the concept of sustainability, while noticing that sustainable development is determined by the triad: economic – social – ecologic, expressed by the built capital – human/social capital – human capital. As part of the study I emphasized the fact that each capital evolves simultaneously: internally (elements and own laws, pre-existence of a series of prerequisites, specific resources and forces, characteristic effects, own self-regulation mechanisms) and externally (interaction with the other two capitals through energy, substance and information mutual fluxes). Within this wholeness, the components, especially those which are far from a (social and economic) balance, export their inefficiency to the less evolved systems or to the future. The essence of sustainable development might be stated as being the maximizing of efficiency and welfare in the context of minimizing resource consumption and safeguarding environment biodiversity;

- With a view to offer a practical guide for the evaluation of the performance of cogeneration equipment, I displayed the overview tables that regard the comparative performance for the two generating sets with cogeneration;

- I carried out a review of the energy potential of the SER available in the Jiu Valley and the option for capitalization.

5.3. Personal practical contributions:

- The calculation methods employed owns an applicative value as it might be generally used in industry for various types of energy consumers;

- The conception of the analytical and experimental devices for expressing the quantity and quality performance of the options explored;

- The theoretical and applicative foundation of cogeneration efficiency when capitalizing the SER in the Jiu Valley through case studies;

- Comparatively emphasizing the performance and feasibility of the options proposed.

- Synthetically displaying secondary energy resources, their classification, the emphasizing of the present-day capitalization opportunities, correlated with the economic, social and environment effects materialized through: energy saving, material means and social labor saving, improvement of the technical and economic indices (productivity, cost price of finite product) of technological processes or aggregates, rational capitalization of combustible waste and decrease of environment impact, generating jobs through employing secondary energy resources;

- As cogeneration is the current solution for efficiently capitalizing energy resources in combustion units, I approached, in my work, aspects that regard cogeneration: advantages and disadvantages of cogeneration, performance and types of cogeneration systems, tri-generation opportunity, and graphic quantification of an option for the efficient energy capitalization of combustible waste;

- With a view to motivate and convince the decisional factors to implement cogeneration, I emphasized the main advantages:

- Energy advantages of cogeneration;

- Cogeneration advantages in the field of preserving the quality of the environment;

- Economic advantages of cogeneration;

- Social advantages of cogeneration;

- Quantity and quality performance increase through tri-generation implementation;

- After an overview of the opportunities for the energy capitalization of biomass, I offered suggestions for the activities required in order to increase the sustainability of the community energy system in the Jiu Valley;

- The existence in the Jiu Valley of an important amount of biogas, which is the result of the processes for treating waste water, made me carry out the energy assessment of biogas and urban waste, based on statistic data, while examining the opportunity for its capitalization;

- For the energy use of natural gas, originating in degassing coal layers, I analyzed the opportunity of employing Stirling engines and heat accumulators with heat tubes;

- With a view to motivating the global energy performance of biomass compared to fossil fuels, I carried out a comparative analysis, based on the assessment of the life cycle of energy (LCEn), on the performance of coal TEPSs and biomass waste TEPSs;

- I carried out the theoretical and applicative foundation of cogeneration efficiency based on SER capitalization in the Jiu Valley relying on the following case studies:

1. Steam bio-generator at a lumber factory
2. Heating system of a group of dwelling places
3. Waste water treatment plant
4. Capitalization of degassing system
5. Capitalization of thermal energy SER

- The case studies under analysis confirm the opportunity for extending the energy systems relying on renewable energy resources and secondary energy resources, performance obtained depending on the scheme of exploitation and the quality of the resources employed;

- Energy performance is similar to the performance displayed by conventional fuels, while environment performance is clearly higher.

Owing to the syntheses presented, the analyses carried out, the case studies concluded and the performance emphasized, my work offers a data base and sets forth a series of development directions for the efficient energy capitalization of the various SER based on biomass.

6. Future opportunities and perspectives

The issue analyzed by the thesis primarily offers suggestions and feasible ideas for a *green option* of decarbonizing the energy system of the Jiu Valley.

CET Paroseni might switch to a mix made of coal and biomass, while developing cogeneration and the network of urban thermal heating system, completed with tri-generation meant for the agri-food production specific for the mountain areas.

Stockpiles' cultivation with energy plants is a feasible solution providing economic – energy – ecological benefits, the argument in its favor being the natural re-vegetation of the old stockpiles.

The development of the system of waste water treatment for all the settlements in the Jiu Valley is going to determine the increase of the energy efficiency of biogas use.

The re-designing of the closed mines might result in systems for the hydro-pneumatic storage of electrical energy during periods of low consumption.

In the case of the mines under exploitation, based on gas availability originating in degassing, while using Stirling engines, they may operate surface equipment that decrease the use of the energy from the National Energy System.

7. Boundaries of research

To conclude, the research objective proposed was carried out after having implemented a series of methods that were considered adequate for the assessment of the energy performance of the options proposed for the capitalization of thermal energy from secondary energy resources. The quantity and quality analyses displayed in the work might be used as a foundation for future researches in the case when the following limitations are considered:

- The analyses mainly focused on the capitalization of biomass waste, a resource that is widely present in the Jiu valley, a fact that does not enable the generalization of the results of the research to other secondary resources of thermal energy;

- The need for energy analyses for more varied samples belonging to the range of secondary resources of thermal energy;
- The taking into account and quantification of the synergic effects linked with the capitalization of secondary energy resources of thermal energy on the three basic goals of sustainable development: economic efficiency, ecologic responsibility and social solidarity.