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REVIEW

of the doctoral dissertation by MR Akhil KUNCHE, M.Sc.

„Computer simulation as a decision-support tool for selecting CO2 emission reduction strategies in the cement industry"

Promoter: **DSc Eng. Bożena MIELCZAREK, University Professor**

1. BASIS FOR PREPARING THE REVIEW

This dissertation opinion, by Mr Akhil Kunche, M.Sc., has been prepared on the order of 08 July 2022 (letter no. W8/498/2022), of the Chairman of the Council of the Scientific Discipline "Management and Quality Sciences" - Prof. DSc Eng. Rafał WERON.

2. EVALUATION OF THE SCOPE OF THE SCIENTIFIC AND RESEARCH PROBLEM IN THE DOCTORAL DISSERTATION

The doctoral dissertation submitted for review, deals with important and current cognitive and research problems in the field of decision support pertaining to formulation of strategies and decisions in cause-effect models, in the field of CO2 emission reduction - in cement industry enterprises. The proposed in the reviewed dissertation model of decision-support tool for selecting CO2 emission reduction strategies in the cement industry is an attempt to eliminate the gap in the existing research that relates to the lack of an individual approach in formulating strategies and making decisions to reduce carbon dioxide emissions in technologically, product-, service- and organisationally diversified cement industry enterprises. The model allows stakeholders in the cement plant to select a combination of strategies to reduce CO2 emissions, depending on the changing political, legislative and also, as observed in the dissertation, conditionings being in line with sustainable development, such as economic, environmental and socially acceptable ones. According to the Author one of the most important factors influencing the adoption of mitigation strategies within the cement industry is the "payback period" of the capital investment. Majority of mitigation strategies require a large initial capital investment to set up the plant and the time it takes for the plant to recover the cost is defined as the payback period.

Therefore, the choice of the subject and object of the study is justified. Cement industry enterprises are characterised by high energy intensity, capital intensity, they are direct as well as indirect producers of greenhouse gases, in particular CO2.

The choice of the topic specified in the title of the dissertation is especially topical, justified due to the multidimensionality of factors shaping CO2 reduction strategies, from the microeconomic perspective of a cement company. The computer simulation model developed in this study can be used as a tool to support decision-making by stakeholders, not only strictly from the cement industry, but also decision-makers in the administrative, financial or political environment. The rationale behind undertaking accurately the research topic is the algorithmisation of various combinations, scenarios, aimed to determine an effective strategy for the reduction, minimisation of CO2 emissions, as well as, from the point of view of reducing the capital intensity of these processes in cement enterprises - cost reduction/optimisation. This directly translates into environmental, energy and also economic security for the group of the investigated cement companies, in macro and micro dimensions respectively. This security can

be defined as forms of multidimensional development and forms of counteracting, minimising or even eliminating heterogeneous threats, especially those arising from the global increase in greenhouse gas emissions. The adaptation and implementation of the System Dynamics (SD) modelling approach is considered to be a research novelty within the scope of the topic defined in the title of the doctoral dissertation. This is a simulation approach characterised by an emphasis on: cause-effect relationships and feedback loops, which is a priority in decision-making processes. The introduction of Causal Loop Diagrams (CLDs) in modelling is evaluated positively.

Referring to the above discussion, carried out in this part of the opinion, I conclude that the research gap, the scientific and research problem, are valid and quite correctly justified. The cognitive and research scope is acknowledged to be interdisciplinary, it primarily concerns the discipline which is acknowledged to be leading in this dissertation - the discipline of management and quality sciences. The added value is recognised the convergence of the cognitive and research scope of the dissertation with the derived scientific discipline of environmental engineering, mining and energy, and, due to the global economic dimension, the convergence with the discipline of economics and finance.

2.1. STRUCTURE OF THE DISSERTATION

In general, the layout of the dissertation is logical. The dissertation consists of 161 typed pages, including abbreviations, bibliography, list of figures, list of tables and three appendices. In order to improve the quality of the work, readability of the research results obtained and the analyses carried out, the author has introduced 51 tables and 54 figures. In the bibliographic portfolio, the author of the dissertation introduces 110 "compact" bibliographic items, including scientific literature from the discipline of management and quality sciences (in particular the thematic scope of the dissertation), statistical periodicals, and legal and administrative acts. Generally, the introduced source materials, including bibliographic items, are thematically convergent with the topic of the dissertation, contained in the title and in its individual chapters.

The main part of the thesis consists of a seven-part Introduction, five thematic chapters and a concluding Discussion section. Two integral parts can be distinguished in this dissertation: the theoretical-cognitive and the empirical ones. The theoretical-cognitive part (mainly Chapters 2, 3 and partly 4) is a search of "source material found", on the basis of which a taxonomy and scientific discussion have been introduced in the following areas: cement

production and CO2 emissions, mitigation strategies for reducing CO2, Decision Support Systems and System Dynamics particulate in the context of Cement Industry for CO2 mitigation/reduction.

The empirical part of the dissertation, on the other hand, is partly Chapter 4 and Chapters 5 and 6. These chapters are a research-analytical study in the scope of experiments and scenario in the scope CO2 emission reduction strategies in the cement industry. A comparative analysis of the defined scenarios affecting differences in CO2 reduction strategies in cement companies has been conducted.

The contents of the two parts of the dissertation are compatible. The theoretical and cognitive part provides a "fairly correctly" structured basis of the research carried out, the analysis of the results obtained and the conclusions drawn.

This opinion also includes an evaluation of the individual chapters of the dissertation, which has been presented below.

In the first chapter **"Introduction"** of the thesis (14 pages), the PhD student attempts to justify the choice of the dissertation topic and the subject and object of the research. He attempts to synthesise the justification of the impact of greenhouse gas emissions on climate warming. He collates the climate pledges of top greenhouse gases emitters, as well as the contributions of heterogonous industries to their emissions. He also justifies the selection of cement companies as those particularly in need of support in developing scenarios and strategies to reduce greenhouse gases emissions, primarily CO2.

In this part of the doctoral dissertation, the author correctly defines, in the context of the subject matter set out in the title of the dissertation, the primary purpose of the work *„(...) identify and assess the impact of various CO2 mitigation strategies applicable for specific cement plant configurations under varying market conditions using System Dynamic (SD) simulation modelling approach (...)".*

According to the author, to carry out the primary goal, a SD model has been developed, implemented and described to represent a typical cement plant with all the significant processes that contribute towards the CO2 emissions through electricity utilisation, fuel consumption and raw material decarbonisation. The introduction also defines a second objective, which I believe is strictly an empirical one: *„(...) investigate the potential for using the chosen simulation method and subsequently demonstrate the utility of the model by comparing the impact of*

chosen mitigation strategies using real world data collected from a reference cement plant (...)". The final section of the Introduction includes a recommendation of the structure of the work and its substantive content - as the result of a theoretical and cognitive query and empirical research and analysis.

The second chapter - **'Cement production and CO2 emission'** - includes 13 pages. The chapter indicates the quantitative and qualitative relationships between cement production and electricity demand and CO2 emissions, for production in wet and dry processes and for intermediate and final products. In this context, the quantitative energy consumption of the production processes for different cement kilns is indicated. In chapter two, the author of the dissertation also presents the mechanisms for reporting emissions in the cement industry. The tangible value of this chapter is the compilation of mitigation strategies for reducing CO2 emissions in the field of cement manufacturing at different stages of implementation, such as Waste Heat Recovery (WHR), clinker substitution, carbon capture, use of alternative fuels and efficiency improvements of energy usage, in the context of reducing CO2 emissions. The compilation of these strategies has been done according to the author on the basis of a literature review. However, the number of references, relevant literature references, due to the nature of chapter two is too modest. Most of the literature items referred to by the author of the dissertation are from the previous decade.

The third chapter entitled - **'Literature review'** covers 23 pages. In this part of the dissertation, the cognitive focus concerns Decision Support Systems (DSS). The first part of this chapter concisely defines this system and the categories of decisions generated in this system. Examples of adaptations and implementations of these systems in areas convergent with the subject of the dissertation are summarised, inter alia such as: the DSS as utilised solution issues related to climate change in domains such as agriculture, forestry, and industries; the DSS for evaluating the impact of climate change on agriculture and forestry; the DSS as spatial, multi-ensemble analyzator , and multi-model simulations at regional scale as well as assessment of adaptation strategies at local scale or the DSS for pollution control in the cement sector.

In chapter three, the author indicates and at the same time justifies the essence of the application of Systems Dynamics (SD), as a component of Decision Support Systems (DSS) in applications within the domain of climate change mitigation. The evolution/development of

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Systems Dynamics is indicated and described. A comparison of different methodologies for modelling decision-making processes, including the SD model, can be positively evaluated (Table 10). In chapter three, the author indicates Causal Loop Diagrams (CLDs) and stock-and-flow diagrams as typically used for the visual representation of SD models.

The cooperation of the author of the doctoral dissertation and the Promoter with regard to the use of a Causal Loop Diagrams (CLDs) in research and in the field of CO2 emission reduction strategies in the cement industry, which is confirmed by the relevant literature references included in this part of the doctoral dissertation, is also positively assessed. The measurable value of the conducted literature review is the recognition of the current state of the Systems Dynamics application in the domain of climate change and CO2 emissions. The analysis of the current solutions and implementations of Systems Dynamics in Cement Industry for CO2 Mitigation is also positively assessed.

Critical remark concerns primarily the title of chapter three. It is too abstract at present. The current title "Literature review" impedes reading the structure of the entire dissertation, since after a detailed analysis of the whole dissertation, a literature review was also carried out in chapters 1-2. The title should be limited to DSS and SD, in particular in terms of CO2 Mitigation in Cement Industry.

Chapter four "**MODELLING PROCESS**" covers 40 pages. This chapter constitutes an attempt to justify the developed mitigation strategies (the causal loop diagram) models analysed in the context of CO2 emission reduction. Modelling incorporates: 1) Captive Power Generation: WHR, Solar Photovoltaic (SPV), and conventional fuels (e.g., coal, natural gas, fuel oil); 2) Clinker Substitution Module: Fly Ash, Wet Ash, and Blast Furnace Slag; 3) Fuel Substitution Module: RDF, TDF, and biofuels (from microalgae ;. 4) Carbon Capture Module: Indirect Carbonation, Carbon Capture and Storage (CCS), and generation of biofuel using microalgae .; 5) Efficiency Improvements Module: For efficiency related upgrades specific to individual cement plan. In this part of the doctoral dissertation, the conceptualization of the model encompassing all the included mitigation strategies applicable to a cement manufacturing plant (Figure 22) is assessed positively. The Causal Loop Diagrams were developed for each adopted strategy, on the basis of which a discussion of transformation in the given areas that these strategies cover was introduced. The author attributes the importance of the discourse carried out on the basis of the CLDs developed and visualised in the scope CO2 emission reduction, among others to: 1) the captive power generation which lead to savings in

expenditure; 2) introduction of clinker substitutes as clinker production is the most emission intensive process within the cement manufacturing plant (through the chemical process of calcination and as well as the thermal energy required by it); 3) utilising alternative fuels like RDF; 4) the indirect carbonation methods which generates by-products that can be sold for recovering a portion of the operational expenditure depending on their market; 5) the modernisation of plant processes which leads to improvement of thermal efficiency, thereby requiring less thermal energy for production of cement - this one is in line with to negative energy concept.

The proposed solutions cannot be treated as a novelty, they are known in the literature on the subject, as well as applied in various economic areas, for example thermal power plants. However, the methodological justification using CLDs modelling is assessed positively as the Author's scientific contribution. At this point, it should also be emphasized that the indicated combustion of RDF is a topic of debate in Europe. In particular, it concerns high-scale combustion technologies, especially regarding thermal power plants. The Author justifies that, certain countries like India have existing policies that provide subsidies for utilising alternative fuels like RDF, which further enhances the financial sustainability of this mitigation approach to reduce emissions. At this point the question arises as to why it is in cement plants that the combustion of RDF is justified economically, technologically and in the context of CO2 reduction.

Based on the analyses and the reasoning, a description of variables, states and flows as well as input parameters and heterogeneous variables used in the basic model and in individual sub-modules – corresponding to the appropriate mitigation strategies CO2 emission reduction were introduced. In this part of the dissertation, readability is hindered by long tables left without explanation. It is believed that appropriate modelling languages, such as UML or even BPM process modelling, commonly used in modelling and designing IT systems would facilitate the presentation. Despite the comments of a debatable nature, chapter four is considered as fundamental and research one in terms of methodology and design.

Chapter five – **„EXPERIMENTS AND SCENARIO DESIGN"** covers only 3 pages. In this chapter, the following issues are described by means of key words only: data used for experiments, base scenario (BAU) end default plant operation mode, low CO2 mitigation effort (LME) and high CO2 mitigation effort (HME).

Basically, in the context of the subject matter specified in the title of the work, making this chapter a separate and autonomous part renders reading the Author's intentions difficult. This chapter should, in my opinion, be part of chapter six on „Results and comparisons".

Chapter six – **„Results and comparisons"** covers 27 pages. In this part of the work, the PhD student justifies the methodological approach of the developed model of computer simulation as a decision-support tool for selecting CO2 emission reduction strategies in the cement industry. With regard to the adopted scenarios and CO2 reduction strategies described and justified in the previous chapters of the present dissertation, the process of validation and testing of the adopted model was carried out in the scope of BAU, LME, HME. Additionally, the payback periods of investment expenditures were calculated, if applicable. The following assumptions have been adopted - which are recognised as a case study: (30% substitution of clinker with BFS or fly ash or wet ash with 5% substitution of clinker (default for ordinary Portland cement); introducing alternative fuels: 10%, 30% substitution of fuel for kiln with RDF and TDF; captive power generation - include 30% from Photovoltaic sources (PV) and rest from regional grid; carbon capture: indirect carbonation using Sodium Hydroxide and Barium Hydroxide is compared with carbon capture and storage). The measurable value of the scientific discussion in chapter six is the comparative analysis of the proposed strategic approaches, according to the following criterion: payback period of various mitigation strategies under different scenarios.

The seventh and the last fundamental part of the doctoral dissertation **"Discussion"** covers 4 pages. The author introduces a scientific discourse attempting to define the final conclusions, which constitute a synthetic summary and justification of the objectives of the doctoral dissertation. A certain deficiency in this part of the work concerns the lack of reference of the formulated conclusions to the relevant analyses – parts of the dissertation (chapters / subsections).

The three appendices are measurable value of the dissertation, which confirm the implementation of the research described in the main chapters of the dissertation: stock and flow diagrams of the model and its sub-models; alternatively, the live model with embedded data for BAU scenario; list of input parameters and datasets used in each scenario.

2.2. FORMAL EVALUATION AND METHODOLOGICAL IMPLEMENTATION OF THE DISSERTATION

The layout of the work, the division into chapters and subchapters in the individual parts is considered to be quite correct. At the same time, the proportions of the individual parts have not been maintained, in particular in the case of chapter 5.

Furthermore, the introduction of an elaborate numbering structure in the chapters (e.g. 2.2.1, 2.2.2), resulted in a dispersion of the content, in the context of the correctly thematically formulated titles of the chapters and their subchapters - this remark is only of a discussion nature.

The introduced visualisation of research results in the form of figures, charts is positively assessed, which strengthens the cognitive and research value of the evaluated dissertation.

The selection of research methods has been quite correctly justified, with reference to the formulated objectives of the work. A novelty in the context of the subject matter of the work specified in its title is considered to be the modelling of CLDs and the developed and tested (with the assumed parameters assigned to the adopted mitigation strategies) computer simulation model as a decision-support tool for selecting CO2 emission reduction strategies in the cement industry.

The weak part of the dissertation is actually the lack of justification for the selection of the research sample, as well as the absence of a description of the research subject (cement plants). It is only implicitly assumed that they were Indian cement plant(s). Such confirmed information would have been important for the evaluation of the dissertation, given the diverse political and economic environment as well as cultural, ethnic or economic diversity. A comparative analysis of Polish/European cement plants with Indian ones would certainly be of added value, of course within the adopted scope of evaluation - CO2 emission reduction strategies.

3. Substantive evaluation

The research carried out and the summarised results of the study, the final outcome of which was the development of a computer simulation model as a decision-support tool for selecting CO2 emission reduction strategies in the cement industry, confirm the realisation, according to the author, of the primary objective of the work: *„(...) identify and assess the impact of various CO2 mitigation strategies applicable for specific cement plant configurations*

under varying market conditions using System Dynamic (SD) simulation modelling approach (...)".

Documentation of realising this objective are mainly Chapters 2 and 3. Because, these chapters, have been developed on the basis of a literature review. The above objective should be described as theoretical and cognitive one.

The second objective formulated by the author in the dissertation under review is to: *„(...) investigate the potential for using the chosen simulation method and subsequently demonstrate the utility of the model by comparing the impact of chosen mitigation strategies using real world data collected from a reference cement plant (...)".*

Chapters 5 and 6 document the realisation of this objective. As they are empirical in nature, it would be appropriate to refer to this objective as an empirical one.

Assuming that chapter 4 is strictly methodological in nature and, according to the author, that SD is a component of DSS and the methodological adaptation of a Causal Loop Diagrams (CLDs) in CO2 emission reduction strategies in the cement industry carried out in the dissertation, allow the introduction in this review of the postulate that it would be reasonable to formulate also a third methodological objective.

On page 40 the author indicates that *"(...) The stakeholders also need to validate the dynamic hypothesis (...)".* However, he does not formulate his own research hypotheses, even if only by indicating the existing (documented by the author in the dissertation under review), relations, relationships, interdependencies, occurring between the introduced mitigation strategies scenarios and CO2 emission reduction in the cement industry. The introduction of hypotheses is not explicitly obligatory, but their formulation/acceptance would certainly have an impact on the final value of the scientific work.

Despite the critical and important remark concerning the research hypotheses, the merits of the reviewed dissertation in terms of content are:

- accurate and practically useful choice of research topic,
- insight and research intuition,
- the author's theoretical knowledge, not only in the field of management, economics, environmental engineering but also in the field of cement industry functioning in a holistic perspective,
- ease of formulating scientific problems, ease of formulating conclusions,
- the quality of the scientific research carried out, and of the visualisation of the research findings and conducted scientific discourse.

4. Evaluations, criticisms and polemics

Having carried out a thorough analysis of the entire dissertation, as well as out of my duty as a reviewer to make a global evaluation of the merits, I submit for your consideration and discussion the following main points:

1. Why, in the dissertation, did the author fail to indicate the relationship or interdependence between CO2 emission reduction strategies in the cement industry and Corporate Social Responsibility (CSR) and sustainable business management strategies? Are there such interdependencies, and if so, to what extent?
2. The dissertation lacks information, reference, literature review on strategic analysis, methods/tools of strategic analysis, typical for the discipline of management and quality sciences. Please explain why these issues have not been addressed in the context of the topic defined in the title of the dissertation?
3. Is the proposed model universal and can it be implemented in European as well as Indian cement companies but also in other industries?
4. Why, especially in cement works, is combustion of RDF justified economically, technologically and in terms of CO2 reduction?
5. Can cement companies be prosumer companies, in line with Toffler's third wave?

Additional remarks include:

1. The lack of clear information about the size of the research sample as well as the surveyed cement companies.
2. The lack of research hypotheses is once again highlighted.
3. Too high a proportion of literature items from the previous decade, in the bibliographic listing. Are there scientific positions in the Polish literature that coincide with the cognitive, methodological and research scope of the doctoral dissertation?

5. Qualification evaluation

The reviewed doctoral thesis deals with an important problem of significant importance, not only cognitive but also economic, in the national and, at the same time, global dimension, regarding the operation of cement companies. The author introduces heterogeneous strategy scenarios, models for reducing CO2 emissions in cement plants. Based on his research, he proposes a computer simulation model in this research area. This model was correctly verified in the doctoral dissertation. Thus, giving the qualification evaluation of the whole dissertation,

I believe that the Doctoral Student has acquired the skills of independent scientific work. Of course, the dissertation evaluation also introduces critical remarks, some of which are of a debatable nature, and it is recommended that these be taken into account in further research work. In making an overall assessment, the dissertation is obviously interdisciplinary in nature, recognising that decarbonisation is a global problem and at the same time analysed in a bottom up approach, starting from the organisational/enterprise level, the leading scientific discipline is that of management and quality sciences.

I conclude that the submitted thesis meets the requirements for a doctoral dissertation. In view of this, **I request that the reviewed doctoral dissertation be accepted and that Mr. Akhil Kinche, M.Sc. be admitted to public defence.**

Robert Kucęba