Uniwersytet Ekonomiczny w Katowicach | Katedra Badań Operacyjnych

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REVIEW REPORT
on the PhD thesis
"COMPUTER SIMULATION AS A DECISION-SUPPORT TOOL FOR SELECTING CO_2 EMISSION REDUCTION STRATEGIES IN THE CEMENT INDUSTRY"
by mgr inż. Akhil Kunche

1 Formal Basis

The review was commissioned by prof. Andrzej Ożychar, Vice Rector of Wrocław University of Science and Technology by the formal notification 5/7/D12/2022, dated on July 8th, 2022. The above notification was based on the resolution of Rada Dyscypliny Naukowej o Zarządzaniu i Jakości nr 101/20/RDND12/2021-2024, dated on July 7th, 2022. The dissertation was written by mgr inż. Akhil Kunche under the supervision of dr hab. inż. Bożena Mielczarek, professor at Wrocław University of Science and Technology.

2 General Characteristics of the Dissertation Content

The PhD dissertation is 161 pages long and contains 7 chapters. The main part is preceded by abstracts in English and Polish, and followed by summary, abbreviations, references, list of figures, list of tables and 3 appendices. The list of references is comprised of more than 110 positions.

The Introduction introduces the background of the undertaken research. The main issue is CO_2 emission and its consequences for climate change. International agreements led to the introduction of new laws and policies to promote mitigation in different greenhouse gas emission domains such as, energy sector, transportation, reforestation, and manufacturing. The cement industry which is a subject of the dissertation belongs to the largest source of CO_2 emission and thus this fact substantiates the topic of the dissertation: decision support for reduction strategies in the cement industry.

The main goal of the research is, " ... to identify and assess the impact of various CO_2 mitigation strategies applicable for specific cement plant configurations under varying market conditions using System Dynamic (SD) simulation modeling approach.". The SD model has been designed to become a support tool for the choice of the emission mitigation strategy in a cement plant. It can also be utilized by policymakers. At the second level a utility of the developed model in the real context has been examined. Finally, the Author presents an evaluation of the various combinations of mitigation strategies under different policy scenarios and market conditions.

Chapter 2 presents the cement manufacturing process and the sources of CO_2. The possible methods of reducing the CO_2 emissions have been enumerated and described in detail.

Chapter 3 is devoted to a literature review. It starts with the discussion of decision support systems and their application to solving problems of climate change. To support the decision process, simulation techniques that examine complex systems are widely used. Among them the special role plays the System Dynamics developed by J. Forrester. As this method has been chosen as a main tool for this dissertation, its basics are described in Chapter 3.2. The further part of Chapter 3 focuses on publications studying applications of SD in climate change and CO_2 emissions. Then, an extensive critical analysis of the existing literature about use of SD for CO_2 reduction in cement industry has been carried out. In the chapter summary the Author indicates a research gap that he intends to fill in in his doctorate.

Modeling process is a subject in Chapter 4. Five specific strategies on mitigation in the cement industry have been chosen and conceptualized in the comprehensive model including five sub-models for each strategy. They are:

- captive power generation,
- clinker substitution,
- fuel substitution,
- carbon capture,
- efficiency improvements.

For technical reasons it constitutes the longest part of the dissertation containing graphical representations of the model and its modules and several tables with the detailed description of variables, stocks, flows, input parameters and exogenous variables. The results of a few techniques that have been used for model validation are presented at the end of the chapter.

To perform experiments on the model three policy scenarios have been designed (Chapter 5). The basic scenario was named BAU ("Business As Usual") in which the current policy and market trends remain unchanged throughout the duration of the simulation period. In the second scenario, named LME ("Low Mitigation Effort"), it is assumed that government policies and market trends slightly favor the implementation of mitigation strategies. The last scenario – HME ("High Mitigation Effort") – is based on the assumption that strongly favor the implementation of mitigation strategies. Additionally the payback period was calculated for all combinations of strategies. The relevant data for experiments are taken from the cement plant in Telangana, India. The operational data for the period 2011-2021 include clinker produced, coal consumed, gypsum consumed, fly ash consumed, average Gross Calorific Value (GCV) of the fuel utilized, specific energy consumption for production of cement (electrical and thermal; includes clinker production), specific energy consumption for production of clinker as a by-product. Future production trends for April 2021 to March 2031, i.e., clinker produced, is determined based on the projected data for cement demand and average plant utilization in India.

Chapter 6 concerns results of simulations and their comparisons. Four individual strategies with a number of variants have been compared with the existing plant configuration. They are:

- Clinker substitution,
- Alternative fuels,
- Captive power generation,
- Carbon capture.

Then, the three combinations of the individual strategies have been also analyzed:

- Clinker substitution and captive power generation,
- Clinker substitution, alternative fuels, and captive power generation,
- Clinker substitution, alternative fuels, captive power generation, and carbon capture.

The results of simulations are presented in a large number of graphs and tables with a detailed commentary.

The main part of the dissertation concludes with Discussion (Chapter 7). For each individual strategy, the most effective (suitable) variant has been identified in terms of potential constraints, emission reduction and plant expenditure. The specific variants are:

- Clinker substitution: wet ash substitution.
- Alternative fuels: Tire Derived Fuels (TDF).
- Captive power generation: combination of Waste Heat Recovery (WHR), Solar Photovoltaic and existing grid.
- Carbon capture: Carbon Capture and Storage (CCS).

If you took into account the cost per unit of CO_2 emission reduction, the second combination, i.e. clinker substitution, alternative fuels, and captive power generation, appeared to be the most promising.

3 General Remarks

The dissertation presented by mgr inż. Akhil Kunche meets the generally accepted standards of valid doctoral dissertations. The research objectives were clearly defined in relation to the research gap identified in the literature study. The conceptualization of the model and its scope are in line with the System Dynamics methodology and has the adequate level of generality. The CO_2 emission is an important problem and has a long-range ecological, social and economic consequences. Because the cement industry is one of the largest emitters of CO_2, building a decision support system that can help the cement plant management in choosing the mitigation strategy under the assumed criteria is of a great practical importance.

3.1 Important Content-related Remarks

1. Research objectives (p. 17), Summary (p. 128): "to identify potentially better approaches that would both minimize emissions and plant expenditure.". The work would obtain a much more solid methodological basis if the simulation results were analyzed in the framework of multiple criteria decision aiding. The above research objective indicates that it is the bi-criteria problem. The formal comparison of solutions against both criteria and identification of non-dominated solutions (supported by graphic representation) would greatly facilitate the decision making.

2. p. 63, Table 19,: In the equation for "Net Policy Cost", the "Net Emissions" in tons are added to integral over income/expenditure in rupee. Such an error can distort the results of the model.

3. Financial criteria in the model: Why has Payback period been used for evaluation of potential strategies? Although there is no perfect measure, the Discounted Payback Period would be a better choice, or even Net Present Value (NPV), especially that high interest rates are to be expected in the near future.

4. Fig. 47-49: What is the source of periodic changes (about 4 in each year)?

5. The expression "the most optimal option" has been used several times (p. 101 and on). It must be avoided in the scientific text. "The optimal" is "the most" by itself.

6. There is large number of various combinations of strategies. How has the preliminary selection been done? What criteria have been applied?

3.2 Minor Remarks and Points of Debate

The remarks listed below are ordered according to appearance in the dissertation, not according to importance.

1. p. 9, below Table 3: The sentence "Given the capital-intensive nature of these methods, the existing policies have not been ineffective in propelling the cement industries to adopt the available mitigation methods" is incomprehensible in the context of the paragraph.

2. p. 31: "The specific energy consumption in the cement plants can be improved by upgrading the plant process to include newer pre-heating system and pre-calciner as it can be seen in Table 7." . How this statement can be derived from Table 7?

3. p. 36: Reference to Ford (1997). It is quite old review. It would be better to use more general and newer publication, e.g. Torres, J. P. (2019). System Dynamics Review and publications 1985–2017: Analysis, synthesis and contributions. System Dynamics Review, 35(2), 160–176. https://doi.org/10.1002/sdr.1628.

4. p. 37, Fig. 17: In my opinion the example of positive causal loop on seems to be too simplified. How can the "Cement availability" (supply) have a direct and positive influence on "Infrastructure demand"?

5. p. 56, Fig. 22: According to the comment on p. 57, in the model presented on Fig. 22, the node "Additives processed for blending into cement" should have positive influence on the node "Plant expenditure on electricity" rather than directly on "Company financial resources".

6. p. 65 Table 20, CAPEX-WHR: It seems that capital expenditure depends on the power of the equipment, so the unit INR/kWh would be more appropriate than INR.

3.3 Editorial Notes

1. Some publications are referred by first name instead of family name. It makes difficult to identify citations.

2. p. 24: "Majority of the modern cement plant installations feature multi-stage preheating systems, as illustrated in Figure 10, ..." . It seems to be Figure 15, not 10.

3. p. 38: text refers to Eq. (1) and Eq. (2) instead of Eq. (3) and Eq. (4).

4. p. 42: "The search strings (1) and (2) fetched ...". Should be (5) and (6); "with Tables 6-11 describing the modules utilized in each study and Table 12 summarizing the studies reviewed. Is the table numbering right?

5. Even though I am not a native English speaker, I dare to point out the misuse of the phrase "in case of" instead of "in the case of" (p. 19, 22, 23, 27, 38, 44, 55, ...). These similar forms have very different meaning!

6. p. 53 "Table 12 indicates the various mitigation strategies adopted by each study, ..." Table numbering?
7. p. 59 "... and Biofuels (producing using microalgae in the carbon capture plant, further described in later sections 3.1.4 and 3.2.4). " Something is wrong with sections numbering!
8. p. 110: "In the HME scenario, a combination of WHR and SPV with the rest procured from grid, as seen in Fig. 44 leads to the least expenditure among the available options.". It seems that it should be LME.

4 Final Conclusion

The dissertation presented by Doctoral Candidate Akhil Kunche meets the requirements of Polish law (Art. 187 Ustawy o szkolnictwie wyższym i nauce z dnia 20 lipca 2018 r. Prawo o szkolnictwie wyższym i nauce /Dz. U. z 2022, poz. 574 z późn. zm./) and may be admitted to further stages of the PhD procedure.

Katowice, August, 25, 2022 *dr hab. Jerzy Michnik, prof. UE*