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Original Paper

Modeling the Environmental Impact of Sustainability Policies in the Construction Industry Using Agent Based Simulation and Life Cycle Analysis

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Abstract

The construction industry, with its long supply chain and long lifetime of projects, is blamed to be one of the main contributors to environmental concerns including accelerated resource consumption and harmful emissions. Industry stakeholders, including developers, designers, contractors and suppliers, are, therefore, continuing to explore different options to reduce this impact. Various approaches have been adopted in different countries with building rating systems like the Leadership in Energy & Environmental Design (LEED) certification program being the most common way reflecting stakeholders' efforts to go green. Governments and concerned authorities at national and state levels are expected to foster the trend of sustainable construction by motivating these stakeholders and pursuing policies that would help the green momentum. However, decision makers at such governmental and state levels face a challenge of prioritizing the policies and regulations that should be imposed. The objective of this paper is to present the development of a framework of an Agent Based Model (ABM) that simulates the effect of different possible policies in the construction market using Life Cycle Analysis (LCA), which is to be used by decision makers to assess and prioritize different policies or combination of policies. The framework was developed using Anylogic software and a sample construction market from the state of Qatar was used as an example for implementing the proposed framework. Results of running the model on this sample market illustrate the effectiveness of using this ABM as a support tool for decision makers in the area of sustainable construction.

Keywords
sustainability policies, sustainable construction, life cycle analysis, agent based modeling

1. Introduction & Research Background

The United Nations Environmental Program report published in 2002, revealed that the construction industry consumes 40% of Europe's energy, in addition to being responsible for a large percentage of the emission of greenhouse gases in the United States (UNEP, 2002). With the construction industry being recognized worldwide as one of the highest contributors to the environmental challenges that our globe faces today, there is a need for the development of high-level governmental policies that motivate companies to adopt sustainability practices in the construction markets. Although businesses and non-for-profit organizations are coming to the conclusion that a sustainable development approach brings value to their institutions (Gilding et al., 2002), the additional costs related to the implementation of sustainability concepts in projects still hinders many decisions to go green. During the last three decades, the international community has witnessed the development of some limited policies that encourage environmental-friendly construction practices (Bosch & Pearce, 2003) by providing incentives (e.g., tax reductions and energy cost relief) for construction projects' stakeholders to minimize the environmental impacts and resource consumption of their buildings throughout their life cycle. However, in order to optimize the effect of these policies on construction markets, there is a need to evaluate the impact of different policy scenarios in a quantifiable way, which enables decision makers to choose and prioritize the enforcement of such policies.

To explore the impact of these developed policies and regulations, a number of studies have looked at the possible impacts of environmental sustainability on construction business practices. Beheiry et al. (2006), for example, carried out an evaluation of the impact of corporate commitment to sustainability on capital project planning and capital project performance. In this research, two indices were developed for measuring the level of corporate commitment to sustainable practices and for measuring the sustainability component of project planning. These two indices were evaluated for 17 Fortune 100 firms in the U.S., concluding that the measurement of corporate commitment to sustainable practices was a feasible tool that enables corporations to balance sustainability and profitability (Beheiry et al. 2006). Another study, by Gomes and da Silva (2005), evaluated at a higher level the impact and effectiveness of sustainable construction practices in the developing economies of Latin America and the Caribbean. One of the important conclusions of the study was that sustainability practices have to be designed and developed on a local level to gauge the main challenges for the region where they are applied in order to consider the special conditions related to that local context. The buy-in of stakeholders at multiple levels was shown to be a determining factor for the effective application of these policies. This includes the will of governments to adopt and encourage sustainability practices both at the state and local levels (Gomes & da Silva, 2005). Some studies have looked at modeling sustainable communities and mapping interactions at different levels between human beings and their environment in order to develop a better understanding of the macro effect. Mani et al. (2005), for example, developed a framework for simulation models that could be used for evaluating the sustainability of building practices, that included the community, the community lifestyle, the community attitude, the built environment, and the community sustainability. Each component describes the features of the overall context under which sustainability practices can be implemented in the construction market. However, the above referenced searched did not include an endeavor to quantify the consequences of implementing sustainability policies in a way that enables high level authorities to take educated and justifiable decisions on implementing these policies.

The main objective of environmental policies is the optimization of outcomes, i.e., the increased sustainable practices in the construction industry. Therefore, it is continuously crucial for decision makers to be able to compare outcomes of different policies in quantifiable terms. Since the outcome is basically the changed level of adoption of sustainability practices at construction projects' level, there is a need for a bottom-up technique that looks into micro level and enables conglomeration of the effect on the macro or market level. The reviewed literature in this area including references in the preceding part of the introduction have focused more onto qualitative techniques for presenting the outcomes of implementing sustainability policies and without a clear road map to enable comparison between these policies. Since the target in this research to close this gap and come up with a proposed framework for modeling these results in a quantifiable way, the authors have investigated the use of Agent Based Modeling (ABM) simulation. ABMs are bottom-up techniques described by North and Macal (2007) as simulation tools used to depict the reactions and interactions of the different system elements, called agents, based on the system inputs that lead to outputs, which can then be reported to decision-makers. This is a perfect fit for the research presented here rather than qualitative endeavors. Also, the agents in ABM, according to Beheiry et al. (2006), are autonomous adaptive entities that have characteristics enabling them to make decisions on their own and to interact with each other.

For implementing the ABM simulation on predicting outcomes of sustainability policies, Hoppe et al. (2007) argued that if regional planning frameworks are to achieve sustainability, a reliable and valid method is needed to measure and monitor the changes associated with sustainability strategies and policies. They also suggested that the methods should provide information about the interactions of ecological and human systems, including the social and economic systems, and their overall impacts on regional sustainability. These assessment methods need to provide information that can be used to guide the decision-making and policy development required for community and regional governance (Hoppe et al., 2007). Further, Hassan et al. (2012) presented a framework for ABM to enable simulation and hence, evaluation of the influence of the different sets of possible sustainability policies in the construction industry. One of the most useful sources that contributed to the development of the subject research work was the work of Dignum et al. (2009) clarified the levels of modeling required for the support of decision-making with respect to policies: macro, micro, and meso; and mainly targeted defining the scope of the meso level and its requirements. The authors, in the aforementioned study, elaborated on approaches to describe the norms and interactions between the different agents and how they can be developed, providing one framework as an example.

The idea behind using ABM in this research is that the overall trend in the market and the decisions taken by main stakeholders are not predefined. Therefore, there is a kind of stochastic nature of the overall consequences of implementing different sustainability policies on the construction market. However, we have some idea of the way individual agents or stakeholders develop their decisions in a project level and how the projects are developing within the construction market. Under these conditions and within the context of sustainability in construction projects, ABM can perfectly serve to simulate the bottom-up effect of the behavior of stakeholders under projects on the overall outcome on a market level. Therefore, the objective of this paper is to develop an integrated ABM to simulate the impact of implementing sustainability policies; the model can serve as an innovative decision-support tool for governmental agencies to assist in identifying the set of policies that lead to optimum reduction of environmental impact by the construction industry.

2. Theoretical Framework

To achieve the objective of this reach, two ABM modules are integrated with a quantification technique that uses environmental Life Cycle Analysis (LCA); the first addresses diffusion of sustainability practices in response to implementing different policies, and the second is a simulation of how sustainability credits are selected to achieve targeted green building certifications.

For the integrated ABM model, the input is set of introduced policies and the output is the consequence of these policies in terms of single Life Cycle Analysis (LCA) score, which represent the potential reduced environmental impact. A sample construction market was used to verify the functionality of this model where set of sustainability policies were introduced for a time period of 6 years and the LCA single scores of the reduced environmental impact for each policy were identified for comparison purpose. Optimization of the results of implementing policies requires thorough understanding of the effects of these policies on a micro-level and hence, providing proper reflection on a market scale. The micro level in this context is the project level where stakeholders interact to make choices of credits that will achieve target certification under any of the rating systems. Currently, there is no available research on modeling of decisions related to sustainable developments.

3. Methodology

Figure 1 illustrates the main steps in the integrated model and the subsequent subsections details how each module works and is integrated to the other model components.

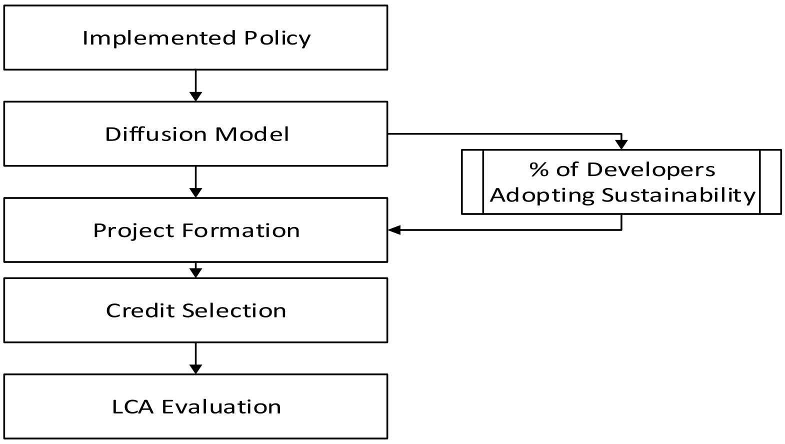

Figure 1. Main Steps of the Integrated ABM Model

Subsections 3.1 through 3.4 includes elaboration on the steps demonstrated in Figure 1. The assumptions behind development and sequencing can be summarized herein before detailed description under each subsection. First, the baseline, representing the status-quo of the selected construction market under analysis, is developed. Then, upon making a decision on a specific policy or changed regulation, the first reaction of the market is modeled under the agent-based diffusion model (as described in Subsection 3.1). The output of this module is represented in terms of a percentage of developers, and consequently construction projects adopting sustainability approaches, leading to formation of "green" projects at different levels (as explained in Subsection 2.2). The model then simulates the consequences of forming these "green" projects into decisions on selection of credits that will satisfy the target sustainability objective of the projects that will be certified as sustainable through selected rating system like Leadership in Energy and Environmental Design (LEED) certification program. Further elaboration of this step is illustrated in Subsection 3.3. The final subsection, 3.4, under the methodology is dedicated to clarification of the final presentation of outcomes in terms of LCA scores, which is developed by the authors according to Attallah et al. (2013).

3.1 Diffusion of Sustainability in Construction Markets

As governments introduce incentives or penalties, developers in the market react by considering increased level of adoption of sustainability in their projects. To simulate that effect on the behavior of stakeholders, Hassan et al. (2012) used the concepts of diffusion theory and ABM. According to this model, sustainability is adopted in the construction market in a way like the adoption of technologies, where different parameters affect the spread of knowledge of the technology and also foster the willingness to commit to these new trends. According to Hassan et al. (2012), the agents are the developers who change their status from non-adopter to partial-adopter, and finally to full-adopter. The basic four parameters affecting the decision of developers to go "green" are as follows:

1) Influence of consultants and project management companies

2) Perceived benefits

3) Lack of financial incentives

4) Lack of readiness of the market

The first parameter reflects how consultants and project managers influence the decisions when they introduce the concepts of green projects and its associated benefits. The second parameter is an indication of the way stakeholders perceive the benefits of adopting sustainable practices on their companies and the society. The third parameter is a reflection of the hesitance of stakeholders to target green certification due to the additional cost associated with design changes. The last parameter addresses the issue of a lack of available construction materials and methods that are required to achieve the targeted scoring.

A comprehensive survey was done by Hassan et al. (2012) covering construction companies in a sample market, and the results of this survey have been used to indicate the level of impact of the above-mentioned parameters on changing the status of developers. Accordingly, a rate of change was assigned to each influencing parameter. Following the same modeling approach and based on the qualitative analysis of the reference survey, which was conducted as part of a large-scale research on sustainability policies, the four different phases of adoption developed were adopted in this study. Figure 2 shows snapshot of the state chart used in the ABM model, which describes the four stages of adoption and the parameters affecting agent behavior, along with the initial policy scenarios used for the case study that will be addressed later in this paper. As indicated in Figure 2, the agents in this model go through the four stages, and this transition is affected by the rates of change of the parameters that are significantly affecting the decision to change from one state to another. The four phases are described as follows:

1) Non-sustainable agents (Non_Sustainable)

Non-sustainable defines the type of agents who are not yet interested in joining the “green” movement. These agents are not yet motivated enough to decide to target certification of their projects.

2) Implementers with no experience (Green NE)

This is the first stage of implementation where the stakeholders make the decision to target certification according to one of the sustainability rating systems. However, since this is their first exposure to design and construction of green projects, they have not yet gained experience in addressing the selection of credits. Therefore, the credit selection process under this phase of implementation will follow more of a random pattern following a simplified cognitive decision style approach. This decision making approach was fully detailed and modeled by the authors in Attallah et al. (2017) where the decision maker (the designer or architect in this case) would use the knowledge he/she has on sustainable construction and green building technologies without specific procedures or established rules within the company’s manual or processes. This adopted cognitive decision-making style leads to selecting credits without systematic prioritization based on the negative environmental effect

3) Implementers with experience level-1 (Green_PrEXP1)

This state reflects more mature handling of sustainable development by stakeholders. With an increased learning curve, the stakeholders are capable of identifying more rational ways of defining sustainability objectives suitable to their projects and matching their project conditions with suitable credits. Therefore, the credit selection process here is simulated using the cognitive decision style for experienced consultants as referred to in Attallah et al. (2017).

4) Implementers with experience level-2 (Green_PrEXP2)

Under this state, the learning curve is at its maximum. The stakeholders are capable of better rationalization of the selection decision based on systematic approaches that are gained by the employees involved in different sustainable projects. Therefore, the selection under this stage is designed to follow the procedural approach following the ELECTRE III method, which is also covered in Attallah et al. (2017). Under this decision-making approach, the projects' stakeholders adopt a systematic way of selecting the sustainability credits. ELECTRE III method, in the reference paper, is developed based on pairwise comparisons between certification categories. This systematic approach leads to selection of priority credits that have are perceived by the decision makers to have the least environmental impact.

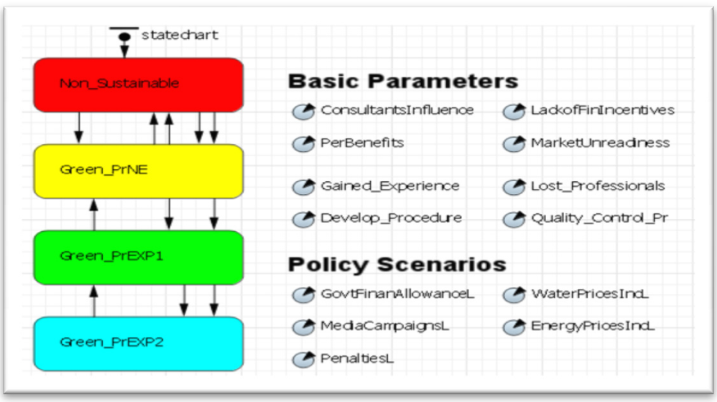

Figure 2. State Chart for the Agents in ABM Model (Screenshot from Anylogic Software)

The ABM simulation is implemented using Anylogic software. The model is designed to accept any number of agents, which will be the population of the ABM. Running the project triggers the creation of a number of agents with the number identified by the users at set up time. Accordingly, the agent class within the model is generated a chosen number of times, and each agent starts with a phase 1-non-sustainable state at the beginning. The time scale in this model is designed as one year, which means that every time unit that passes the time scale of Anylogic represents one year of behavioral changes that can lead to changes from one state to another. The state change is based on the four basic parameters described earlier, and four additional parameters identified through the reference survey analysis that are relevant to this component of the model. Table 1 illustrates the additional parameters that were identified through the survey analysis.

Table 1. Additional Agents Behavior Parameters Identified by the Survey

Parameter	Behavioral Change	Effect
Gained Experience	This behavior represents the development of accumulated experience due to involvement in sustainable projects over time. The agents change their behavior of credit selection from a random pattern to clearer methods of selection.	Positive
Developed Procedures	Over time, experienced stakeholders develop procedures of credit selection. These procedures are adopted by employees based on set criteria and weights defined through the ELECTRE III approach.	Positive
Loss of Professionals	This parameter represents loss of knowledge of credits due to turnover of experienced employees. This happens as the cognitive decision approach counts on the person's knowledge and accumulated experience.	Negative
Quality Control Issues	Agents lose control over the procedures used for selection due to issues with quality control or non-compliance with agreed manuals. This negatively affects the transition from the cognitive selection to the procedural decision approach.	Negative

The initial status of the modeled construction market is captured through running the base line, which reflects the impacts of the basic and additional parameters without any incentives. Policies are then represented by parameters that can also affect the behavior of stakeholders and were measured through the survey results. To clarify this, rates associated with changes in agent state due to the effects of these policies were derived from the questions in the structured survey held with industry professionals. Examples of the policies that can be implemented in construction markets are in Table 2.

Table 2. Examples of Policy Scenarios

Policy Scenario	Description
Governmental Financial Allowances	This policy represents financial incentives offered to stakeholders adopting sustainability approaches in their projects. Incentives here include reducing taxes on project transactions, reducing custom fees for materials involved in the project, and reducing building permit fees.
Water Price Increase	Increasing the price of main resources in some contexts could be an incentive for developing ways of reducing consumption. Water is one of the main elements under all sustainability rating systems.
Media Campaign	This policy is non-monetary. Increase in awareness pertaining to environmental threats on society is a positive factor for increased adoption of sustainability in projects.
Penalties	Penalties, like financial fines, are usually the last resort for governments to push for minimum levels of implementation. These policies, by default, lead to increased adoption of sustainability on projects.

According to the above described mechanisms for the behavioral changes of agents, the percentage of developers targeting certification under rating systems with different approaches change over time. The number of agents at the different implementation phases over time periods is the output of this component of the model. Figure 3 shows an example of a sample market of 25 agents, all of them starting at being non-sustainable, which is the number of red agents at time 0. The numbers of implementers with no experience and implementers with level-1 and level-2 experience are recorded into variables as shown in the figure.

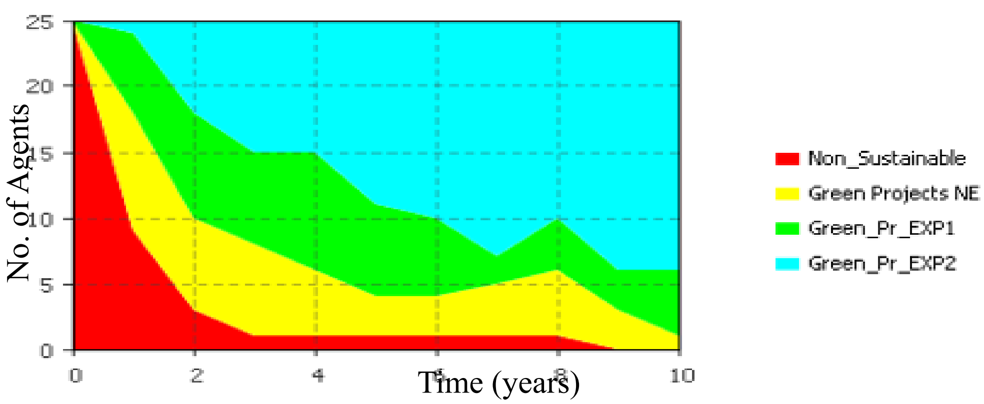

Figure 3. Example of Diffusion Output—Base Line (Screenshot from Anylogic Software)

3.2 Project Formation

The results of the diffusion module under the presented integrated ABM are basically the numbers of adopters of sustainability at the different described levels at the end of the model run time. Upon making the decision to adopt green practices, stakeholders of every project start acting based on the project parameters, and their own attributes. Project formation is an important step in the model that links the diffusion module to the other model components. Although the work of Hassan et al. (2012) designated developers as the agents in the model, the integrated model presented in this paper was built assuming that every developer will be building one construction project per time step, which is taken to be one year. However, the model can easily be modified to reflect different arrangement of project allocations based on actual data from the construction market to be modeled. Also, the model was designed to accept two main constraints from the user:

1) Projects Budget

The project budget is a main determinant factor guiding selection of credits for certification due to the additional costs associated with changing design and construction plans. Therefore, the overall value of projects to be executed in the construction market during the simulation time is an important factor. The designed model allows users to change this total market value. This type of information can be available to users of the model from government statistics or from specialized trade magazines that survey the market and identify projects at the planning or bidding stages. Such periodicals publish the projects expected and their value as well, which is a typical source for the data required here. For this modeling effort, the overall budget is evenly distributed over the number of generated projects. However, the model can be fed with different mechanisms of budget allocation based on the demand and actual data collected by the user.

2) Project built-up area

The work of LCA evaluation as detailed in Attallah et al. (2013) is the basis for the final module of this integrated model. Since most of credits base their calculations on the built-up area of the buildings, especially the critical ones that include energy credits, the built-up area is chosen to be a way of scaling the LCA single score of the implemented credit. Therefore, the user is asked to enter the total built-up area of the projects, which is available at the very early stages of any project planned to be executed in the modeled market. Similar to the project's budget, the built-up area is evenly distributed over the number of projects. This can be adjusted to reflect more factual data of the market to be modeled.

3.3 Utilization of the Credit Selection Model

The projects formed in the previous module have certain attributes that significantly affect the credit selection process. Figure 4 shows these main attributes. These project criteria are assigned to projects in the model based on the available information of the market. In the case study discussed at the end of this paper, the projects are assigned based on an even distribution, allowing eight different types of combinations. Consequently, for every project generated, there is a set of attributes assigned to that project, which leads to determination of the selected credits following the methodologies described under the credit selection model according to Attallah et al. (2017). Table 3 shows the allocation method followed based on the agent state. Developers adopting sustainability but having no previous experience are deemed to follow the cognitive approach based on the non-experienced consultant attribute, which leads to higher randomness in the selection process. Projects exhibiting level-1 experience follow the cognitive approach with an experienced consultant, which leads to a more structured selection with closer matches to the project attributes and the nature of the credits. The level-2 experience projects follow the ELECTRE III methodology in selection.

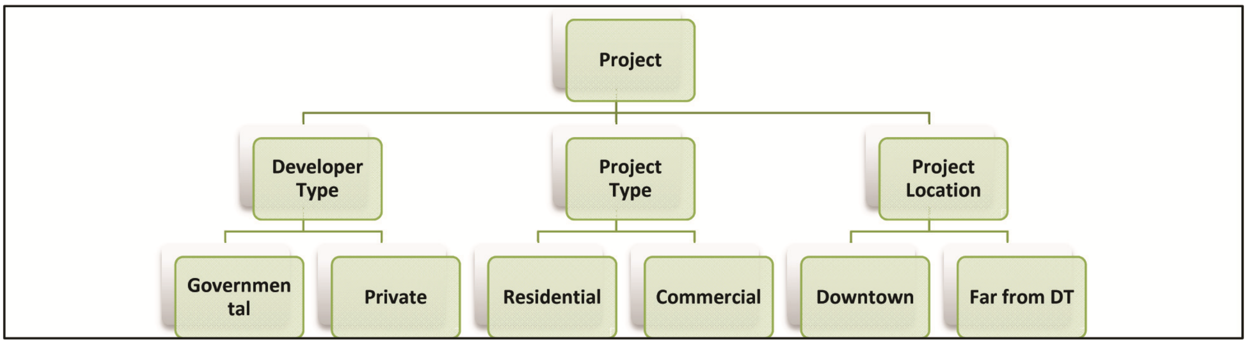

Figure 4. Project Attributes for Credit Selection

Table 3. Allocation of Selection Methods Based on Agent State

Agent State	Selection Methodology
Non-Sustainable	NA
Green NE	Cognitive and Non-experienced Consultant
Green EXP1	Cognitive and Experienced Consultant
Green EXP2	Procedural (ELECTRE III)

3.4 Integration with LCA Evaluation Methodology

The last module in the integrated ABM is the link with the LCA evaluation methodology detailed in Attallah et al. (2013). This methodology is basically a quantification method that aims at determining the potential saved environmental impact that is achieved by implementing any of the credits within the common rating systems in terms of LCA single score. The objectives of the present research include exploring possibilities to quantify the impact of sustainability policies for comparison purposes. In this case, the intended comparison is to be carried out by high-level management within government agencies or leading environmental authorities. Therefore, the reported measures of impact should be as simplified as possible. The output of the credit selection module, which is described under subsection 3.3 are basically sets of credits selected for each of the projects being executed in the construction market to be modeled. This type of information cannot be easily interpreted by high-level decision-makers. Therefore, the step of converting all credits to be perceived on the same scale is deemed mandatory for the purpose of this research.

The LCA evaluation methodology developed is used to interpret the effect of implementing credits in terms of LCA language, hereby referred to as the single LCA score. The outcome of the LCA evaluation methodology on Qatar Sustainability Assessment System (QSAS—a rating system that is developed in the state of Qatar and works in a similar way to LEED) as detailed in Attallah et al. (2013) was taken as the basis for calculations in the case study discussed in this paper. It is worth reiterating here that, for more accurate results, several projects could be analyzed using the LCA evaluation methodology and therefore take an average of the LCA scores for the different credits. LCA evaluation under this module depends on the relative built-up areas of the reference project and the new generated ones. These values have been used to estimate the LCA single score for the selected credits in the integrated model by scaling with reference to the built up area of the project in the model compared to the built up area of the sample project in the case study. The reference LCA single scores per square meter for QSAS credits, which are taken as references in the developed model, are listed in Table 4.

Table 4. LCA Single Score for QSAS Credits

Credits	LCA Score per m^2
Urban Connectivity (UC)	
UC1	22.30
UC2	26.75
UC3	12.07
UC4	0.77
UC6	10.49
UC7	5.25
UC8	3.65
UC9	2.63
Site (S)	
S1	7.90
S2	53.09
S3	0.04
S4	3.95
S5	0.03
S6	0.00
S7	2.97
Energy (E)	
E1	2.31

	E2	1.65
	E3	3.16
	E4	0.00
	E5	0.52
Water (W)		
	W1	15.10
Materials (M)		
	M1	6.25
	M3	3.07
	M4	5.20
	M5	6.25
Indoor Environment (IE)		
	IE1	11.41
	IE2	0.12
	IE3	7.48
	IE4	16.53
	IE5	5.40
	IE8	4.05
	IE10	5.40
Management and Operation (MO)		
	MO3	5.98
	MO6	9.02

The single LCA score is unit-less since this is a summation of weighted scores under the different LCA impact indicators, which have different units. However, since this research work is based on using the Eco-indicator 99 databases, the numbers in this table can be referred to as points under the Eco-indicator 99 system. Also, some credits of QSAS are not shown in the above table since they could not be quantified. The quantification index discussed in Attallah et al. (2013) discusses the reasons for the inability to translate the effect of some credits into LCA language.

Calculation of the corresponding single LCA score for the set of credits selected under each of the projects generated is carried out through Anylogic functions and simple coding in association with spreadsheets embedded in the model. Once the model is run, agents or projects are generated; they are then assigned different attributes representing different project conditions. The credit selection process takes place based on the changing state of the agents thereafter. Finally, the credits are evaluated through the last module and single score data are aggregated into variables that are represented in a graphical format. Figure 5 illustrates a sample of the results upon running the simulation. The graph here represents a base line case with no imposed policies. The impact, in terms of a single LCA score is measured at 2, 4, and 6 years. These can be changed by the user as required by the decision-makers who will benefit from this model.

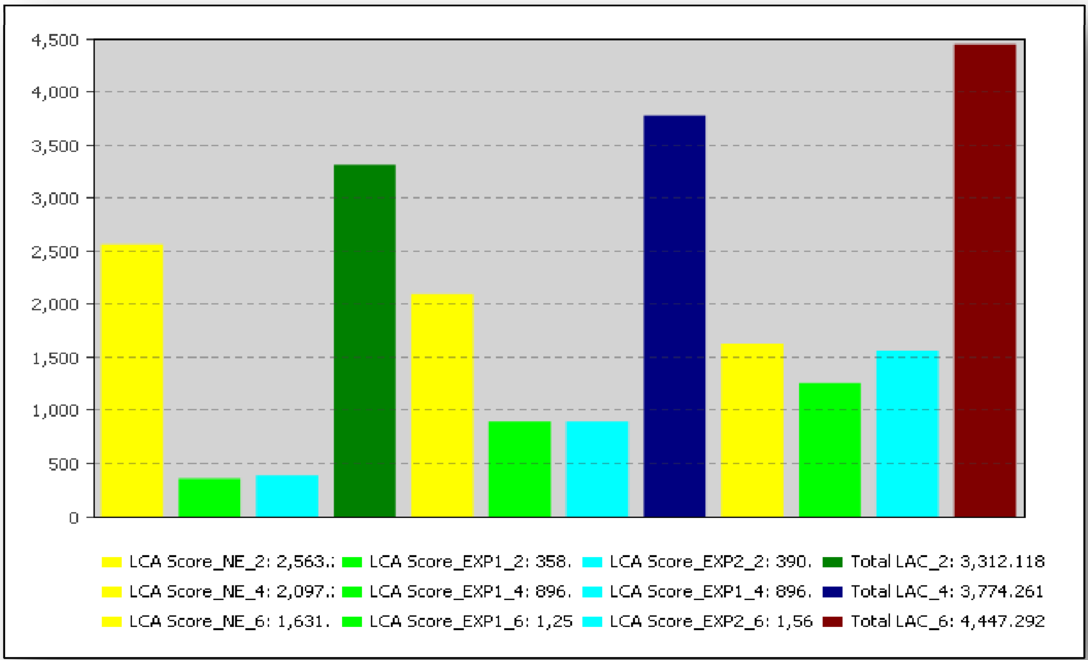

Figure 5. Single LCA Score for 2, 4, and 6 Years (Screenshot from Anylogic Software)

Figure 6 shows a snapshot taken during the run time of the model. The left part of the screen shows the input fields for the total budget and the built-up areas for the market to be modeled, in addition to the spreadsheets embedded in the model and used for calculations. The stack chart on the top left represents the development of a number of agents at the different implementation stages. The red color represents non-sustainable projects. The yellow color indicates implementation with no experience. The green and cyan colors indicate projects that are adopting sustainability with different degrees of experience. The events, functions, and variables shown on the reference screen shot are all used for transferring model information between Anylogic and the spreadsheets and to perform modeling steps as explained. The bar chart shown on the screen shot summarizes the LCA single score for the different stages of implementation starting at adoption with no experience. The total score for the simulation years are also depicted in that chart to allow comparison of the results. A detailed legend is provided under the single score bar chart to clarify the meaning of each bar value.

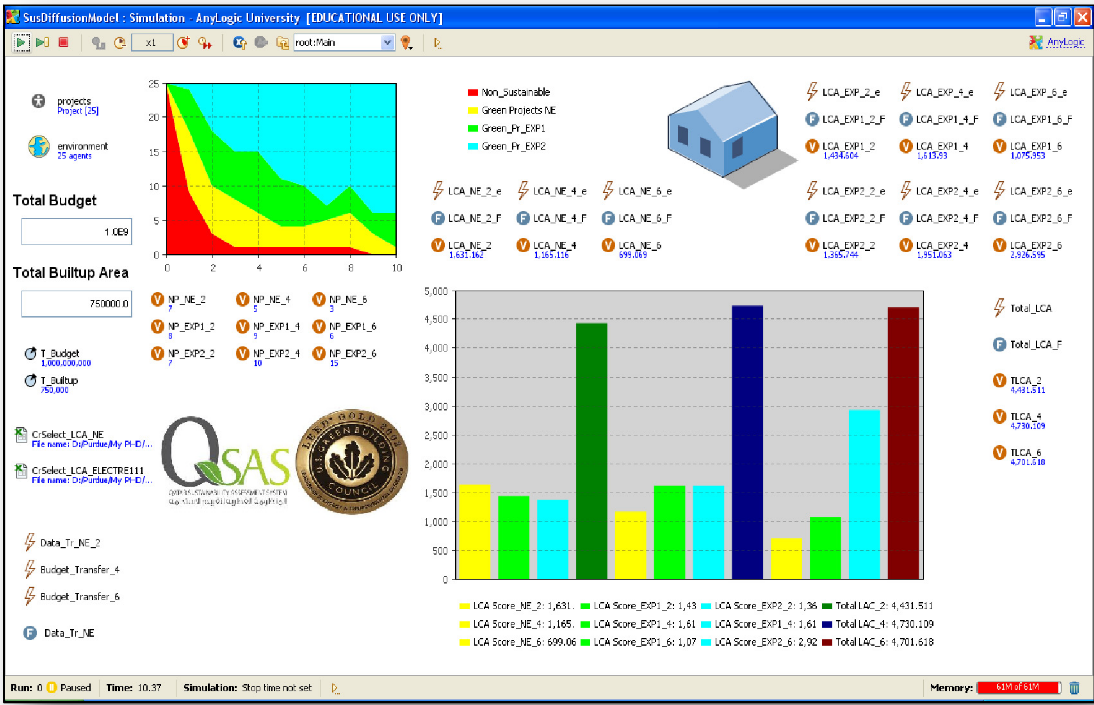

Figure 6. Snapshot during Simulation (Screenshot from Anylogic Software)

4. Case Study—Qatar's Sustainability Policies

In order to verify functionality of the proposed integrated model, a small size construction market in Qatar was considered for simulation. This sample market included 25 construction companies with which interviews were conducted and the results of these surveys, which is the data for the model, were used for this case study. Accordingly, QSAS credits were used and a model was run for five policy scenarios. These policies are described under subsections 4.1 through 4.6 and they are suggested as approaches to encourage the construction companies to adopt sustainability in projects. Each policy will represent the first input to the diffusion model and the final result will be the prospected saved environmental impact through the LCA lenses as explained in the methodology section. The data collected from the referenced survey were used for each of the various policy scenarios in the model developed using Anylogic and the model was run for results for each case. Following are the results obtained for the different policies in graphical format and then discussions of the results obtained in this case study.

4.1 Policy 1: Financial Incentives to Developers

Under this policy, the government motivates stakeholders by financial incentives including reduced taxes on income from green projects. In Qatar's case, taxation is not a very critical issue since the country adopts free taxes for many economic sectors to attract more investment. Other incentives include reducing the fees for building permits and reducing customs charges on imported construction materials. Figure 7 shows the single LCA score results upon adopting the above policy. As illustrated in this graph, LCA single scores for 2, 4, and 6 years are calculated. Also, the scores corresponding to implementation by stakeholders with and without experience are monitored for analysis purposes.

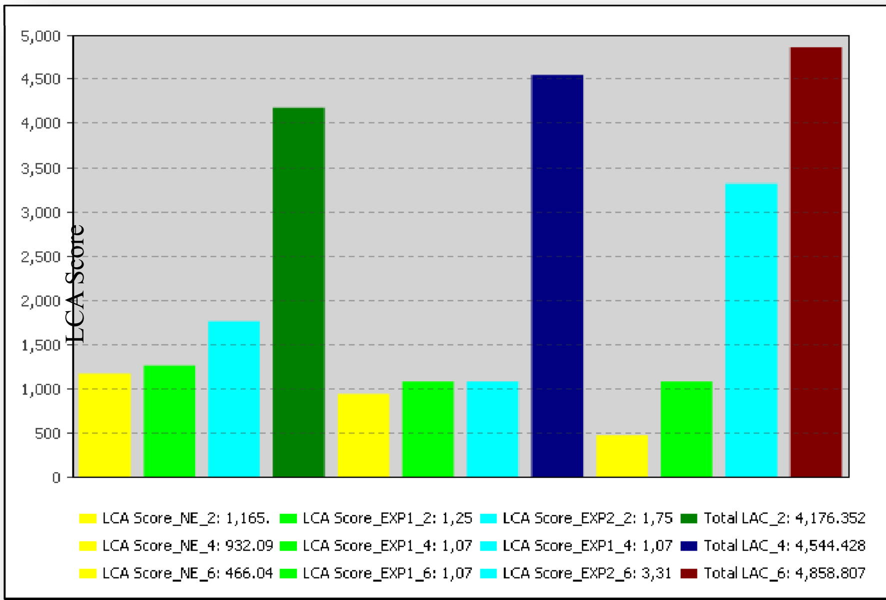

Figure 7. Impact of Financial Incentives

4.2 Policy 2: Increase of Water Prices

This policy addresses a very important element of sustainability in construction projects, which is the consumption of water, being a very valuable resource. Currently, the law allows Qatari citizens to consume water at no charge. Therefore, introducing this policy can be quite effective in the rationalization of consumption and a considerably sustainable design approach for construction projects. Figure 8 shows the results of imposing this policy over six years.

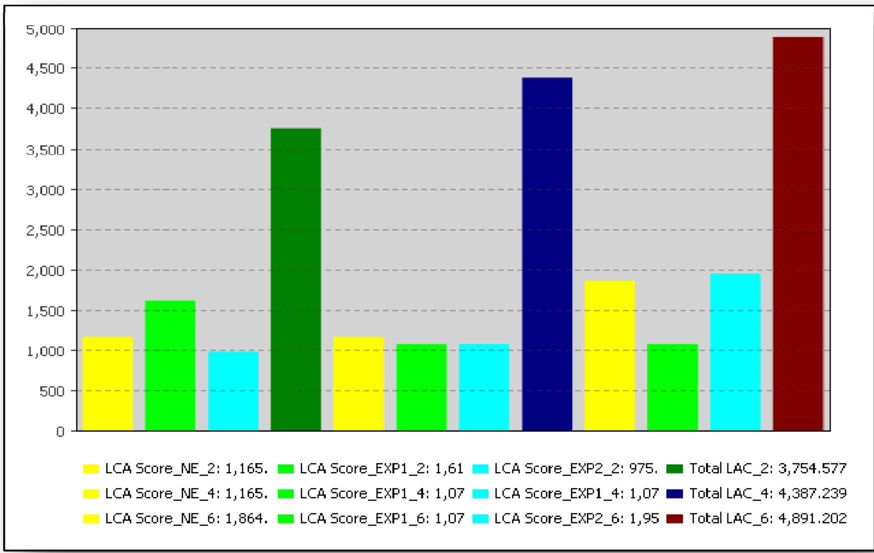

Figure 8. Impact of Increasing Water Prices

4.3 Policy 3: Media Awareness Campaigns

One of the main factors affecting adoption of sustainability is, in fact, the level of awareness among project stakeholders of the environmental issues. Most companies target maximization of profit as the main or primary goal. The concept of corporate responsibility has not been nurtured enough to educate stakeholders about the serious consideration of environmental problems. This is why media campaigns aiming at raising this awareness can play a very important role, especially in societies where corporate responsibilities are not given enough attention. The results of the survey conducted indicated the considerable possible effects of such campaigns on adoption levels. Figure 9 shows the single LCA score results upon implementing this policy scenario in the subject case study.

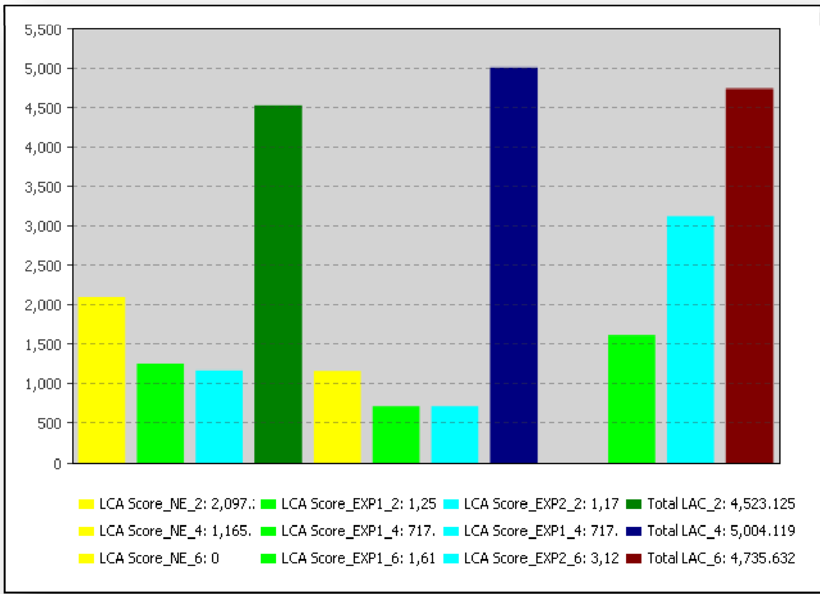

Figure 9. Impact of Media Awareness Campaigns

4.4 Policy 4: Increase of Energy Price

Energy represents the most critical resource for any society. Although the demand for energy is considered somehow elastic (meaning that the demand level is not highly affected by the price), increasing energy prices can push stakeholders to reconsider many areas during the design. Figure 10 shows the single LCA score results upon implementing this policy scenario in the subject case study.

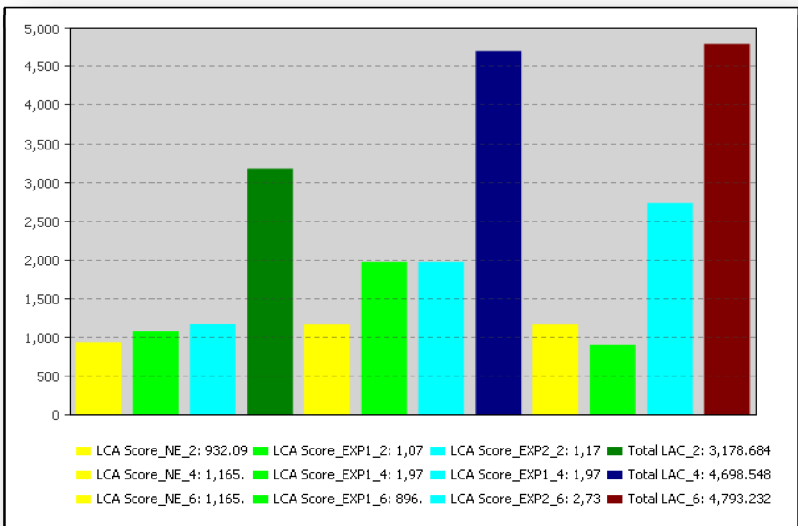

Figure 10. Impact of Increasing Energy Prices

4.5 Policy 5: Penalties

One of the last resorts that governments could pursue is to apply penalties, mainly financial, on projects which do not meet minimum levels of commitment to sustainability approaches. This policy is considered a severe strategy and is not expected to be considered unless there are drastic environmental conditions that cause threats to human life. Figure 11 shows the single LCA score results upon implementing this policy scenario in the subject case study.

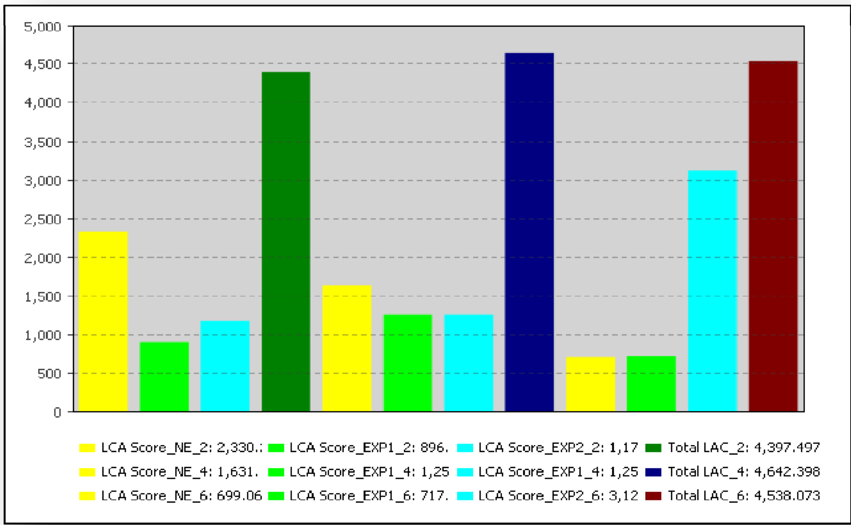

Figure 11. Impact of Imposing Penalties

4.6 Combined Scenarios: Example

Policy planning can exceed the mere selection of one policy. In fact, there could be a five-year plan or even more that includes implementation of waves of policies that enhance adoption of sustainability and maximize the potential reduction of environmental impacts. One example of these plans was run through the developed ABM for the selected case of Qatar. Figure 12 shows the possible time-plan implementation of different policies over six years. The government would launch this plan with media campaigns to spread awareness among project stakeholders. One year later, financial incentives, including reduction of taxes, custom duties, and other burdens can be introduced. Then, energy price can be increased before water price increases one year later. Finally, penalties could be imposed on companies not committed to the minimum levels of sustainability designs.

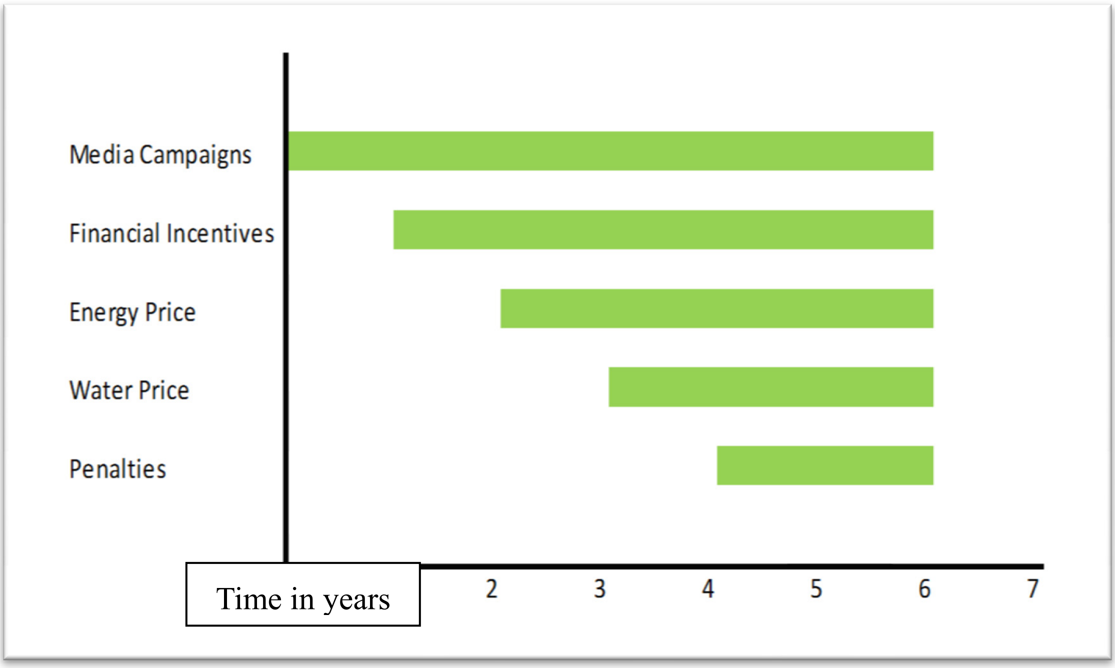

Figure 12. 6-Year Policy Plan

Figure 13 shows the LCA single scores for the 6-year policy plan. As can be seen, due to the addition of several policies simultaneously after year 1, the achieved results are higher compared to single policies. The model is designed to allow policymakers to try different plans on different time scales through changes of events and variables that are embedded in the projects class. These sets of events and variables combine the effect of different policies based on set time frames, and therefore allow these policies to collectively affect the behavior of stakeholders as required.

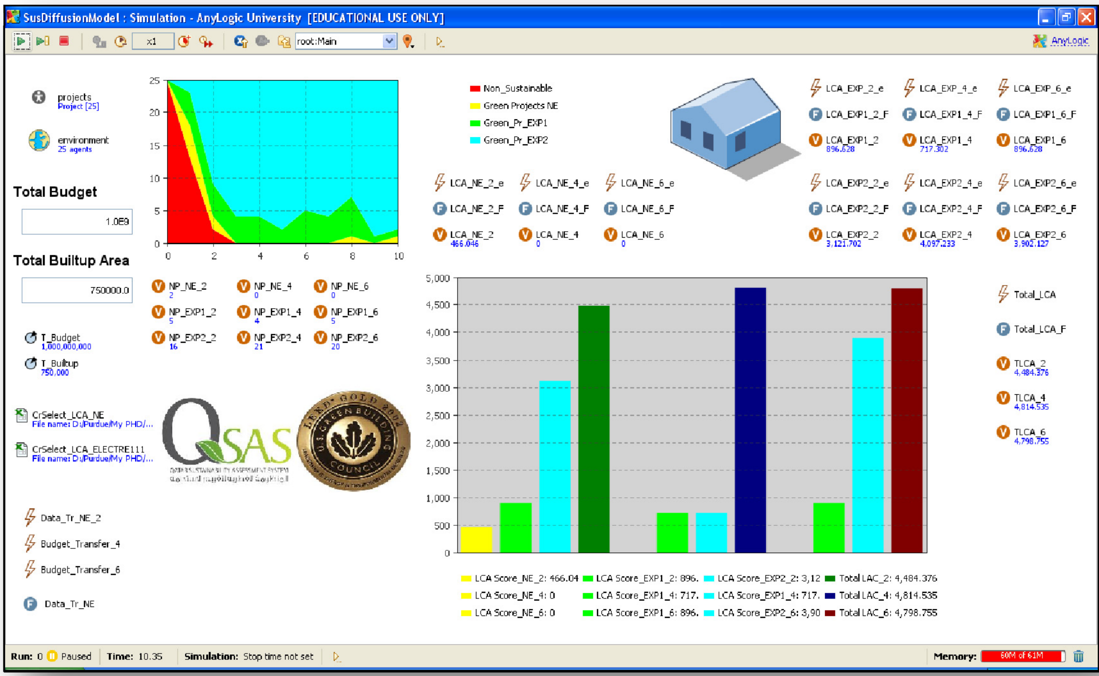

Figure 13. Results of Implementing a Six-year Policy Plan

5. Discussion of Results

The integrated model in this paper is designed to work as a decision-making support tool. The model can provide decision-makers with measurable impacts of adopted policies in terms of single LCA scores. This is important for high levels of authority or governmental officers who are not usually familiar with details of calculations and will find it hard to interpret the numbers that come out of life cycle analysis. As seen in the charts produced in each scenario, the dark green, blue, and brown bars represent the total single LCA scores at years 2, 4, and 6. These could be taken as more convenient references for comparison purposes. Table 5 shows a comparison of the single LCA scores as the impacts of implementing different policies over six years. The aggregated results indicate that all the policies lead to better results in terms of higher potential reduced impact on the environment than the case of the base line from an LCA perspective. The results are indicative of the magnitude of the positive impact that implementation of the discussed policies can have in quantifiable terms. The best result in this case study is expected through the adoption of nationwide media awareness campaigns that attract the attention of project stakeholders to the long-term effects of construction projects on their lives and the health of their children. Perhaps, this is attributable to the fact that sustainability is still a new concept in the state of Qatar and the need is very high to raise awareness. Consequently, intensive efforts could lead to considerable results as the model output indicates here.

Table 5. Single LCA Score for Policies over Six Years

Policy	Single LCA Score			
	Year 2	Year 4	Year 6	Total
Base Line	3,312	3,774	4,447	11,533
Governmental Incentives	4,176	4,544	4,858	13,578
Increasing Water Prices	3,745	4,387	4,891	13,023
Media Campaigns	4,523	5,004	4,735	14,262
Increasing Energy Prices	3,178	4,698	4,793	12,669
Penalties	4,379	4,642	4,538	13,559

Among the proposed policy scenarios, increasing energy prices leads to the least reduced impact on the environment compared to other policies. In the case of Qatar, this could be attributed to two main factors. The first is that energy follows an inelastic pattern in terms of supply and demand, where the demand is not considerably affected by increased prices due to the criticality of this resource, especially in a very hot country such as Qatar. Air conditioning, for example, is an extremely critical element of any construction project there and has to be given sufficient attention in order to meet the comfort expectations of the end users. The second reason is that this country is rich in natural gas, which does not make it easy to raise awareness regarding energy consumption practices. It is also noted that the reduced environmental impact does not necessarily increase with time. This is attributed to the stochastic nature of the model and the fact that, at stages, there could be reductions in the number of implementers and changes in the selection methodologies, leading to sets of credits with less single LCA scores. Although the research methodology might sound as an oversimplification of the calculations, it is important to take more steps towards simplifying the technical messages to policy makers and to show numbers that can be used as tools for supporting decisions.

Moreover, for optimum utilization of this model, two main points should be considered:

1) Since the allocation of project budgets and built-up areas are important parameters in the calculations involved in the developed model, collection of actual project data to run during the simulation would be helpful. This data can be obtained from authorities responsible for registering projects or periodicals that provide business information to construction companies including suppliers, contractors, and others as part of business development activities.
2) Due to the stochastic nature of developing the state of different projects, which is a characteristic of ABM; and due to the embedded randomness of selection of credits under one category, running the same scenario for several times can produce slightly different results; therefore, averaging the results could possibly better simulate the actual market scenarios.

6. Conclusion and Recommendations

The objective of the work presented in this paper is to model the overall impact of sustainability policies in measurable terms. The model was developed using Anylogic software, Version 6.6, university edition and spreadsheets built into the model. The overall model integrated a diffusion module, which aims at measuring the level of adopting sustainability approach in construction projects based on the effect of different policy scenarios. The output of this module, that is the number of stakeholders implementing sustainability at different adoption levels, is the input to another module that aims at the generation of projects with different implementation levels and different attributes. Then, for each of these projects, sustainability credits are selected based on the credit selection model. Finally, the selected credits are evaluated through a LCA approach and single LCA scores are identified for each implemented policy over the simulation years. The model was run to simulate the impacts of different policies and their combination for a time period of 6 years, and the LCA single scores of the reduced environmental impact for each policy were obtained and analyzed for a case study of a small construction market in the state of Qatar. The model was capable of providing different output LCA scores, i.e., providing recommendations on prioritizing the policies and regulations that should be imposed. Accordingly, the developed model contributes the following to the body of knowledge; (1) new methodology to quantify the impact of implementing sustainability policies for supporting decision making related to prioritization of these policies; (2) new modeling technique to simulate the behavioral changes of development companies, project managers and consultants in the process adopting sustainability in construction projects. Furthermore, the model is proposed as a decision-support tool aimed at assisting decision-makers at governmental levels to optimize positive results for sustainability policies imposed on construction markets through analysis of the expected potential consequences of each policy. The model's implementation to specific scenarios or situations will be subject to following similar assumption to those stated in this paper and utilized for the development of the different modules in the presented model. It is recommended that the model is used by authorities that are interested in optimizing the effect of implemented policies on encouraging the construction markets to adopt more sustainable approaches. The model is flexible to be customized for specific market conditions and to reflect variations of set priorities in terms of credits or categories of credits.

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References

Attallah, S., Kandil, A., Senouci, A., & Al-Derham, H. (2013). Utilization of life cycle analysis to evaluate sustainability rating systems for construction projects with a case study on qatar sustainability assessment system (QSAS). *Smart and Sustainable Built Environment*, *2*(3), 272-287. https://doi.org/10.1108/SASBE-03-2013-0017

Attallah, S. O., Kandil, A., Senouci, A., & Al-Derham, H. (2017). Multicriteria Decision-Making Methodology for Credit Selection in Building Sustainability Rating Systems. *Journal of Architectural Engineering*, *23*(2), 04017004. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000244

Beheiry, S., Chong, W., & Haas, C. (2006). Examining the business impact of owner commitment to sustainability. *Journal of Construction Engineering and Management*, *132*(4), 384. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:4(384)

Bosch, S., & Pearce, A. (2003). Sustainability in public facilities: Analysis of guidance documents. *Journal of Performance of Constructed Facilities*, *17*, 9. https://doi.org/10.1061/(ASCE)0887-3828(2003)17:1(9)

Dignum, F., Dignum, V., & Jonker, C. (2009). Towards agents for policy-making. In *Multi-Agent-Based Simulation IX* (pp. 141-153). Berlin Heidelberg: Springer. https://doi.org/10.1007/978-3-642-01991-3_11

Gilding, P., Hogarth, M., & Humphries, R. (2002). Safe companies: An alternative approach to operationalizing sustainability. *Corporate Environmental Strategy*, *9*(4), 390-397. https://doi.org/10.1016/S1066-7938(02)00108-2

Gomes, V., & da Silva, M. (2005). Exploring sustainable construction: Implications from Latin America. *Building Research and Information*, *33*(5), 428-440. https://doi.org/10.1080/09613210500218891

Hassan, M., Kandil, A., Senouci, A., Alderham, H., Cai, H., & Elgafy, M. (2012). *A framework for modeling the adoption process of construction sustainability policies: An agent-based simulation approach*. CIB W78 2012 Conference, Beirut, Lebanon.

Hoppe, P., Rickson, R., & Burch, D. (2007). Governing rural landscapes and environments: The strategic role of local community and global corporate partnerships. In L. Cheshire, V. Higgins, & G. Lawrence (Eds.), *International Perspectives on Rural Governance: New Power Relations in Rural Economies and Societies*. London UK: Routledge.

Mani, M., Varghese, K., & Ganesh, L. (2005). Integrated Model Framework to Simulate Sustainability of Human Settlements. *Journal of Urban Planning and Development*, *131*(3), 147. https://doi.org/10.1061/(ASCE)0733-9488(2005)131:3(147)

North, M., & Macal, C. (2007). *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation*. Oxford UK: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195172119.001.0001

United Nations Environmental Program (UNEP). (2002). *Industry as a partner for sustainable development*. United Nations Environmental Program publications and reports, Brussels, Belgium.