IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Agent-based modeling of multi-scale systems for sustainability assessment – evaluating resource depletion**	
Project Number	**IMURA0504**	
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Research Academy Themes:

Highlight which of the Academy's Theme(s) this project will address?
(*Feel free to nominate more than one. For more information, see www.iitbmonash.org)*

1. Advanced computational engineering, simulation and manufacture
2. Infrastructure Engineering
3. Clean Energy
4. Water
5. Nanotechnology
6. Biotechnology and Stem Cell Research

The research problem

Sustainability is defined as the development that meets the needs of the present without compromising the ability of the future generation to meet their own needs. Achieving sustainable development requires the consideration of economic, environmental and social indicators. This topic goes beyond the traditional areas of engineering design, and encompasses the environmental and social implications of technological decisions. This makes the problem multi-disciplinary. For example, promoting the use of

biofuels must consider its impact on fuel cost, forest systems, and rural agriculture. Moreover, such problems are highly multi-scale in nature. Technology design and implementation decisions are taken by the individual company/industry, and yet we need to understand the regional, national, as well as global implications of such decisions. Additionally, large time-scales must be considered to capture the impact of decisions. Examples include the impacts of greenhouse gas emissions and diminishing resources or resource availability. This brings in the challenge of multiple scales (temporal as well as spatial). In systems science terminology, these are known as complex systems. There is a significant need to develop model based tools to aid and optimize decision making in such cases.

Model based decision making is well established in the field of engineering. However, traditional modelling approaches are not equipped to capture the multi-disciplinary and multi-scale characteristics that become important for sustainability related issues. Agent-based modeling, one of the tools to analyse complex systems, provides these capabilities, but has not been applied to problems of engineering design. The proposed project will address this research gap by illustrating the concept through a specific case study of resource depletion.

Resource depletion is one of several mid-point indicators used for Life Cycle Assessment. However, unlike Global Warming Potential (GWP), Acidification Potential or any of the other "direct" environmental indicators, resource depletion provides a measure of rate of depletion, but without assigning any economic or environmental consequences to it. It therefore stands apart from the other environmental indicators and its importance is often discounted.

In work just finishing at Monash University, an alternative approach has been taken to Resource Depletion that considers the consequence of resource depletion (Rimos et al, 2014a,b). Using natural gas (NG) as a case study, all of the different users of natural gas are considered in a system representing Australia. Different users include the residential, industrial, mining and electricity sectors, with process simulations used to provide the environmental and economic data. In the scenario of natural gas scarcity, the best available resource is substituted and the impacts of the substitution are calculated. This analysis made on a national scale gives the direct impact of natural gas depletion (eg GWP: $t_{CO2e}/t_{NG\ consumed}$). Results are regional and would be different for the US, Europe or India.

Project aims

A new project would aim to take this concept, but extend it to investigate regional energy supply taking into account different substitutions, between forms of energy and uses of energy. Dynamic responses to different scenarios would enable the model to determine the importance of the rate of depletion, which is not accounted for by Rimos et al. We will also connect decision making at individual plant level to regional trends so as to establish the time-frame for this substitution.

It will be necessary to develop agent-based models for this complex, integrated technological-economic-ecological system. These systems evolve over time in the presence of uncertainties, and the components adapt dynamically to achieve the desired objectives. The agent-based approach allows the modelling of such complex behaviour, and is therefore preferred over the traditional equation based approach. Established modelling tools such as MATLAB can be used to develop such models.

The model development will be followed by developing specific scenarios to simulate. This includes scenarios such as increased consumption of different fossil fuels, replacement of non-renewable sources with renewable sources, increasing manufacturing rate, and increasing efficiencies of different technologies. Implications of policy development will also be considered.

1. Rimos, S, Hoadley, A.F.A, Brennan, D.J. 'Environmental consequence analysis for resource depletion'

PSEP, in press, http://dx.doi.org/10.1016/j.psep.2013.06.001
2. Rimos, S, Hoadley, A.F.A, Brennan, D.J. 'Determining the economic consequences of natural gas substitution', Energy Conversion and Management 85 (2014) 709–717.

Additional reading material:

1. Ottino, J. Chemical engineering in a complex world: Grand challenges, vast opportunities. *AIChE Journal, 57*(7): 1654–1668, 2011.
2. Stouffer, D., Ng, C. & Amaral, L. Ecological engineering and sustainability: A new opportunity for chemical engineering. *AIChE Journal, 54*(12): 3040–3047, 2008.
3. Fiksel, J. Designing resilient, sustainable systems. *Environmental Science & Technology*, 37: 5330-5339, 2003.

Expected outcomes

The expected outcome includes an alternative measure of resource depletion for the energy sector and more broadly sustainability impacts based on scenarios leading to policy recommendations. The work will also aim to develop new modelling approaches to model these complex technological-economic-ecological systems. That will be the theoretical contribution of the work.

How will the project address the Goals of the above Themes?

The proposal work will be based on using advanced computational engineering and simulation techniques to solve the problem of sustainable development. While the theoretical and conceptual development will be generic, the specific problems relates to energy supply and use. Therefore, the applications might cover many of the Academy's themes.

Capabilities and Degrees Required

List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.

Successful completion of this research will require the following skills:

- Basic training in engineering
- Strong mathematical foundation
- Experience in simulation modeling
- Experience in data collection, interpretation, and processing, and their integration with models.
- Interest in allied field such as ecology, policy, social sciences, and humanities
- Interest in working on inter-disciplinary problems

Potential Collaborators

Please visit the IITB website www.iitb.ac.in OR Monash Website www.monash.edu to highlight some potential collaborators that would be best suited for the area of research you are intending to float.