Resources, Conservation & Recycling 127 (2017) 244–245

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Towards "climate-proof" industrial networks

Raymond R. Tan[a,*], Kathleen B. Aviso[a], Anthony S.F. Chiu[a], Michael Angelo B. Promentilla[a], Luis F. Razon[a], Ming-Lang Tseng[b], Krista Danielle S. Yu[c]

[a] *Center for Engineering and Sustainable Development Research, De La Salle University, 2401 Taft Avenue, 0922 Manila, Philippines*
[b] *Department of Business Administration, Lunghwa University of Science and Technology, No. 300, Section 1, Wanshou Road, Guishan District, Taoyuan City, 333, Taiwan*
[c] *School of Economics, De La Salle University, 2401 Taft Avenue, 0922 Manila, Philippines*

ARTICLE INFO

Keywords:
Industrial networks
resilience
climate change adaptation

The closure of a number of oil refineries, pipelines, and chemical plants in Texas, USA during the peak of Hurricane Harvey's fury last month underscored the vulnerability of industrial facilities to extreme weather events. The full extent of economic damage and losses resulting from the hurricane still remains to be determined, but will be inevitably greater than immediate estimates, as the effects of the disruption cascade through the supply chain linkages that characterize today's complex industrial systems. Such losses will include damage to capital stock, opportunity costs from lost production, and adverse impacts on quality of life in affected communities, in addition to human casualties. While the destruction caused by the hurricane is by no means a unique occurrence (as demonstrated by concurrent heavy flooding from monsoon rains in India, Nepal and Bangladesh), the frequency of such events is widely expected to increase as a result of anthropogenic climate change. With atmospheric CO_2 concentration having been above 400 ppm for several years now, climate change adaptation measures to deal with shifts that are already bound to occur in the future are just as critical as climate change mitigation strategies for managing emissions of CO_2 and other greenhouse gases (GHGs).

There has been a strong trend towards the implementation of sustainable development initiatives in both developed countries and emerging economies, taking into account both the supply (production) and demand (consumption) sides of economic systems. Examples of specific frameworks used to underpin such measures include industrial ecology (and specifically industrial symbiosis), circular economy, and process integration. These concepts all share a common feature of emphasizing the interaction between system components and proposing loop-closing strategies to reuse/recycle material and energy streams that would normally not be fully utilized in traditional, single-pass industrial systems. This principle can be applied at different scales. For example, process integration is typically applied at the enterprise level, industrial symbiosis at the industrial cluster level, and circular economy at the regional or national scales. Effective application of these frameworks to industrial systems generally reduces resource and emissions intensity, thus allowing for growth in economic output to be compatible with environmental considerations. There is a notable contrast in the use of top-down and bottom-up policies to facilitate such initiatives in different countries (Liu et al., 2017).

Despite the clear benefits, it has been noted that such highly integrated systems are also highly susceptible to cascading failures due to the interdependencies of their subcomponents. Also, the inherent lack of redundancy in networks that are optimized to achieve efficiency (i.e., minimum resource input and waste generation per unit of product output) further increases their vulnerability to disruptions. For example, the closure of a plant in an eco-industrial park affects not just other firms along the supply chain; other plants in its industrial symbiosis network will be affected as well. Furthermore, in highly integrated systems with high levels of cyclic linkages, feedback loops will have the unfortunate effect of amplifying the magnitude of disruptions within the network (Haimes and Jiang, 2001). Such risks may affect current systems, and also deter corporate participation in much-needed sustainable development initiatives. In other words, the very measures needed to mitigate climate change are themselves highly vulnerable to climatic impacts that are already occurring. Thus, we believe that there is a significant research gap on the development of "climate-proof" industrial networks for the future. Significant shifts in climate can occur within the decades-long operating life of a typical industrial plant. Furthermore, climatic impacts are not limited to just sporadic extreme

* Corresponding author.
E-mail address: raymond.tan@dlsu.edu.ph (R.R. Tan).

http://dx.doi.org/10.1016/j.resconrec.2017.09.010
Received 3 September 2017; Received in revised form 10 September 2017; Accepted 10 September 2017
Available online 18 September 2017
0921-3449/

weather events, but can potentially manifest in more insidious ways, such as rising sea level or decrease in freshwater availability, highlighting the need to integrate temporal considerations when developing solution strategies.

The community represented by *Resources, Conservation and Recycling* is in a strong position to make significant contributions to bridge this research gap. Some specific opportunities that are immediately clear are:

- Development of mathematical and computer models to provide decision-making support for planning climate-proof industrial networks. Both descriptive and prescriptive approaches are called for, using mathematical programming and multiple-attribute decision making (MADM) techniques. In addition, modelling of the interaction among multiple decision-makers in these networks via game theory or agent-based modelling (ABM) is necessary.
- Rigorous empirical analysis of impacts of recent climatic events on existing industrial networks using classical statistics and data analytics.
- Standardization of social and financial impact characterization methods corresponding to emissions and chemical releases.
- Understanding non-linear effects on how the impacts of industrial network disruption change as scale changes, taking into account the different types of uncertainty as interdependent systems exhibit more complexity given the spatial and temporal scales involved in climate change policy.
- Development of universally applicable metrics for industrial networks which include indexes for flexibility, robustness, resilience and reliability.
- Exploring how such concepts as "antifragility" (Taleb and Douady, 2013) and highly optimized tolerance (HOT) (Carlson and Doyle, 2000) can be applied to planning industrial networks that strike a balance between efficiency and resilience. In addition, it should be possible to draw insights from network features that lead to national-scale economic resilience (Xu et al., 2011), and to apply these to industrial networks at any scale.

How big is the gap in the literature? Search of the Scopus database using the keyword "climate-proof" yields 69 documents. Aside from two early papers from the 1980s applying this concept to agricultural systems, most of these articles have been published from 2005 onwards, and typically pertain to urban systems and infrastructure. Further refining the search by using both "climate-proof" and "industrial networks" as keywords yields only two publications; both of these papers focus on energy production. Thus, there is clear bibliometric evidence of the sparsity of the scientific literature on this important topic. This gap presents an urgent challenge to the *Resources, Conservation and Recycling* community to contribute concepts and tools to aid in the development of the sustainable, climate-proof industrial networks of the future.

References

Carlson, J.M., Doyle, J., 2000. Highly optimized tolerance: robustness and design in complex systems. Phys. Rev. Lett. 84, 2529–2532.

Haimes, Y.Y., Jiang, P., 2001. Leontief-based model of risk in complex interconnected infrastructures. J. Infrastruct. Syst. 7, 1–12.

Liu, Z., Adams, M., Cote, R.P., Geng, Y., Li, Y., 2017. Comparative study on the pathways of industrial parks towards sustainable development between China and Canada. Resour. Conserv. Recycl. http://dx.doi.org/10.1016/j.resconrec.2016.06.012. in press.

Taleb, N.N., Douady, R., 2013. Mathematical definition, mapping, and detection of (anti) fragility. Quant. Finance 13, 1677–1689.

Xu, M., Allenby, B.R., Crittenden, J.C., 2011. Interconnectedness and resilience of the US economy. Adv. Complex Syst. 14, 649–672.