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Emergy-based life cycle assessment (Em-LCA) for sustainability appraisal of infrastructure systems: a case study on paved roads

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Abstract Civil infrastructure systems are critical assets that are subjected to damage, service-life deterioration, and increasing maintenance and rehabilitation cost. Effective infrastructure management and principles of sustainable development can help to find an optimal compromise between economic growth and environmental protection for all stakeholders. Colloquially, sustainability refers to meeting triple-bottom-line (TBL) performance objectives including environmental protection, economic prosperity, and social acceptability and equity as a result of short- and long-term policy decisions. In this paper, a comprehensive framework based on the integration of emergy synthesis and life cycle assessment (LCA) has been investigated for a public infrastructure system. The main purpose of the applied method, emergy-based LCA (Em-LCA), is to facilitate an informed decision making process for different asset management scenarios, by identifying and quantifying the attributes of TBL impacts over the life cycle of a civil infrastructure system. As a case study, Em-LCA framework has been applied to evaluate the sustainability of two different scenarios for a road construction project in interior British Columbia, Canada. The results indicate that Em-LCA offers a good understanding to address sustainability issues in infrastructure systems and provides quantitative and transparent results to facilitate informed decision making for asset management.

Keywords Sustainable infrastructure · Emergy · Life cycle assessment (LCA) · Road system

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Introduction

Civil infrastructure systems (CIS) (e.g., roads, bridges, water supply, and wastewater and transit systems) have been developed to respond to the increasing demands of growing population, rapid urbanization, and the need to establish safe and sustainable urban and inter-urban infrastructure facilities. They provide basic and core services at municipal, regional, provincial, and federal levels and are critical for any country's socioeconomic development (Lounis et al. 2010).

The CIS are exposed to aging effects, obsolescence, and deterioration during their service lives, increasing demand, fast urbanization, transit plan changes, and random extreme events such as floods and earthquakes. The consequence of these pressures can lead to deficiencies in the condition of assets, and reduction in their capacity and levels of service over time. As a result, these assets become overstressed and may fail before the end of their design lives. Furthermore, the consequence of these burdens can increase the risk of failures (e.g., fatalities, injuries, health problems, vehicle damage, and traffic congestion) which in turn can have serious impacts on the environment, public safety and health, economics, and the remaining service life of assets. To conduct effective infrastructure management, all these issues must be addressed holistically to ascertain the short- and long-term TBL impacts on the CIS's service life (Horvath 2009).

Development of modern civilization depends on construction and development of new infrastructure, planning and optimizing the usage of finite resources, and applying new industrial products and materials. As a result, infrastructure design and planning has become a cornerstone of sustainable development. Sustainability of CIS is a key challenge facing planners, policy makers, asset managers,