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# Evaluating the environmental sustainability of biomass-based energy strategy: Using an *impact matrix* framework

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ABSTRACT

A roadmap for a more sustainable energy strategy is complex, as its development interacts critically with the economic, social, and environmental dimensions of sustainable development. This paper applied an *impact matrix* method to evaluate the environmental sustainability and to identify the desirable policy objectives of biomass-based energy strategy for the case of Alberta. A matrix with the sustainability domains on one axis and areas of environmental impact on the other was presented to evaluate the nexus effect of policy objectives and bioenergy production.

As per to our analysis, *economic diversification*, *technological innovation*, and *resource conservation* came up as the desirable policy objectives of sustainable development for Alberta because they demonstrated environmental benefits in all environmental impact categories, namely *climate change*, *human health*, and *ecosystem*. On the other hand, human health and ecosystem impacts were identified as trade-offs when the policy objectives for sustainability were energy security, job creation, and climate change. Thus, bioenergy can mitigate climate change but may impact human health and ecosystem which then in turn can become issues of concern. Energy strategies may result in shifting of risks from one environmental impact category to another, and from one sustainable domain to another if the technical and policy-related issues are not identified.



## 1. Introduction

Fossil fuels are the main cause of many of the environmental impacts that limit human wellbeing. Biomass has recently drawn interest for use as a low impact renewable resource. Bioenergy is being integrated in the energy strategy of several jurisdictions as a means of addressing sustainable development (European Commission, 2012; House, 2012). However, a roadmap for energy strategy is complex, as its development interacts critically with the economic, social, and environmental dimensions of sustainable development (Veltman et al., 2010). As the driver for energy production is diverse, problems can shift from one impact to another impact, or from one dimension of sustainability to another.

It is imperative that sustainability strategies in the energy sector identify technical and policy-related key issues of concern and knowledge gaps. Key issues of concern are the environmental trade-offs or harms of energy production. Knowledge gap refers to understanding of the barriers and opportunities of energy production in the specific region. Specific policies that promote the generation of energy from renewable sources rather than from fossil fuels, can reduce GHG (greenhouse gas) emissions as well as result in benefits to human health (Haines and Dora, 2012). However, energy strategies are complex and may result in problem shifting (Cespi et al., 2014; Solli et al., 2009). Actions should not shift the risks from one environmental impact category to another, or from economic &/or social domains to the environmental domain of sustainability (Fakhraei et al., 2014; Remais et al., 2014). While the drivers for bioenergy production are diverse, these studies also focused primarily on climate change mitigation policies (Bradley, 2005; Cherubini et al., 2009; James and Network, 2009; Weldemichael and Assefa, 2016). Although in most situations development of renewables result in low environmental impacts, potential negative results should be considered in the energy strategy development (Moore and Jordaan, 2010).

Identifying key issues of concern and relevant environmental policies of sustainability has traditionally relied on the outcomes from expert panel discussions (BC Committee on Bio-Economy, 2011; European Commission, 2012; House, 2012; Singh, 2012; Wang, 2009). This challenge is evident in the literature because existing frameworks for sustainability assessment of systems are limited in fully handling the various policy drivers that are associated with energy strategy planning (Morrissey and Browne, 2004; Ekvall et al., 2007; Štreimikienė et al., 2009). With the exception of the life cycle sustainability assessment (LCSA) framework (Swarr et al., 2011) covering environmental, social and economic aspects, the authors are not aware of any other

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comprehensive alternative framework for sustainability assessment. LCSA is hampered by data availability, cost, and time.

The province of Alberta in Western Canada, which is both the largest emitter of GHGs and strong economic powerhouse of Canada is an interesting to study, mainly as its economy depends on fossil fuel resources, and therefore face serious environmental sustainability setbacks. Main barriers for renewable energy development in Alberta are known to be, among others, information and policy barriers (Kralovic and Mutysheva, 2006). Evaluating the environmental sustainability of bioenergy can assist stakeholders in formulating a proactive energy strategy, implementing energy sector related policies, and responding to sustainable economic development requirements. The main objectives of this study were to investigate the technical and policy-related (i) key issues of concern, (ii) desirable policy objectives, and (iii) develop a framework for bioenergy strategy planning.

## 2. Methodology

This study developed an *impact matrix* framework to evaluate the environmental sustainability of a bioenergy strategy (Fig. 1). The framework for *impact matrix* reflects the life cycle thinking of systems analysis. It includes Scope definition, Literature review, Impact assessment, and Interpretation phases.

### *2.1. Scope definition*

We examine the environmental impact of a bioenergy strategy for the case of Alberta. Generally, impact categories can be defined at the

- Characterization factor: e.g. kg of CO2 emission;
- Mid-point: carcinogenics, non carcinogenics, respiratory inorganics, global warming, ozone layer depletion, acidification, eutrophication, smog; or
- Damage level: climate change, human health, and ecosystem.

Human health impact is a sum implication of the mid-point impact categories of carcinogenics, non carcinogenics, and respiratory effects.

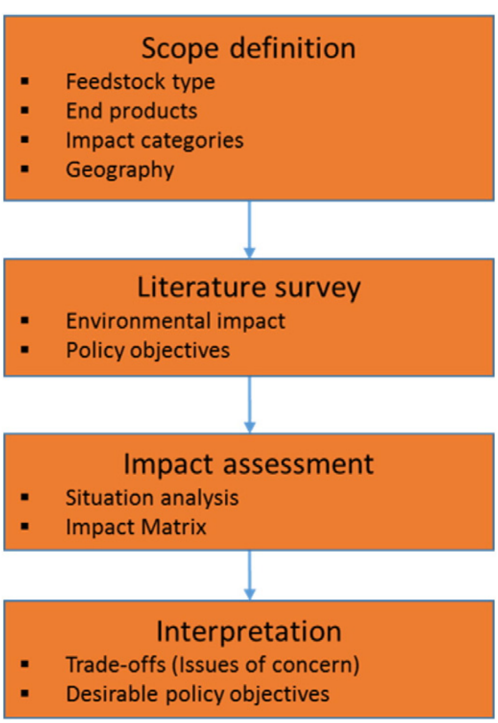


**Fig. 1.** *Impact matrix* framework for environmental sustainability assessment.

On the other hand, ecosystem impact category is a sum implication of acidification, eutrophication, and ecotoxicity. Climate change impact category is indicated by global warming mid-point category.

The scope of this study includes woody biomass feedstocks of forest tree, forestry residue, and unmerchantable wood of municipal solid wastes. Bioenergy refers to the end-products of electricity, heat and fuel. These are analyzed with regard to climate change, human health, and ecosystem impact categories at the damage-level.

### *2.2. Literature survey*

Sustainability is the process of preserving the economic, social, and environmental systems of a product (Munasinghe and Cutler, 2004). According to Munasinghe and Cutler (2004), the economic domain focuses on maximizing the flow of incomes to improve human welfare while at least maintaining the stock of assets that yields these beneficial outputs. The environmental domain deals with preserving the overall viability and normal functioning of natural systems by protecting the integrity and resilience of environmental al systems. Social capital aims at preserving the overall viability and normal functioning of social systems.

We conducted an extensive literature survey to gain understanding on the sustainability of bioenergy systems. The review process was conducted systematically by answering two research questions: "What are the sustainability related policy objectives for bioenergy production?" and "What is the environmental impact of bioenergy production? ". In this study, a *policy objective* is understood as the driver for energy strategy. The literature survey was carried out via *Environmental Design* and *Environmental Science* databases. The search engines Compondex and Google Scholar were used to access all relevant literatures from peer reviewed journals. Additionally, Google was used to access open access studies and reports. The keywords biomass, impact, electricity, heat, fuel, low carbon economy, energy strategy, policy, sustainability, and systems analysis were used to search relevant literatures. Agricultural crops and livestock feedstocks were excluded. Our search produced 276 relevant studies. These studies were further screened based on only studies in the English language that were published in 1995 and latter. On the other hand, only studies that were published in 2005 and latter, and include bioeconomy, strategy, policy, sustainability, and biomass were considered to screen the sustainability related policy objectives. This is because most bioeconomy blueprints were integrated into a jurisdictional growth planning after year 2005. This screening step for policy objectives yielded 18 studies. After applying all these screening criteria, 48 relevant bioenergy studies were analyzed. These studies had examined the environmental impacts of bioenergy for different regions across the world. Over 9 methodological studies were also considered in understanding the environmental sustainability of bioenergy.

Next, we identified six major sustainability policy objectives, namely *energy security*, *economic diversification*, *creating jobs*, *technological innovation*, *climate change mitigation*, and *resource conservation*. Next, the environmental impact of bioenergy from the surveyed studies was inventoried into a matrix table at general level (See Tables A-C of the supplementary material). Thus, the type of environmental impact was first assigned qualitatively as positive or negative in the cells of the matrix table through an integrated view of the general nexus between bioenergy and a policy objective. Positive and negative impacts demonstrate the general environmental effect of bioenergy, signifying beneficial and harmful impacts respectively.

### *2.3. Impact assessment*

#### *2.3.1. Alberta's situation analysis*

Use of a matrix method in policy formulation is not well understood because it involves subjective judgements for evaluating impact significance (Ijäs et al., 2010; Pastakia and Jensen, 1998). Thus, this study