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Canadian oil sand extraction: Exploring the nexus between economic development and environmental sustainability☆

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ABSTRACT

This paper investigates the nexus between environmental sustainability and economic development in Alberta's oil sands industry, focusing specifically on air quality. Alberta hosts the world's third-largest oil reserve after Saudi-Arabia and Venezuela. The government is moving ahead with extracting large quantities of unconventional oil from bituminous sands, processes which produce significant amounts of greenhouse gas emissions (GHGs) (i.e., CO_2, CH_4, N_2O and HFC). We assemble a dataset using available statistical compilations of GHGs in Alberta. We undertake preliminary data analysis with the aim of formulating an Environmental Kuznets Curve. Finally, we propose an original indicator set that frames the relationship between Gross Domestic Product (GDP) and GHGs, which we name the *Sustainable Income Index.*

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1. Introduction

Most world economies are driven by the combustion of fossil fuels. The heat produced is used directly or employed to generate electricity. During combustion, however, large quantities of carbon and hydrogen are converted into carbon dioxide (CO_2) and water (H_2O), the presence of which has significant environmental implications.

The energy sector accounts for approximately 40% of global CO_2 emissions. The International Energy Agency (IEA, 2015) reports that three quarters of these emissions originate from six economies: China, the United States, the European Union, India, Russia and Japan. Coal-fired plants account for just 40% of world energy production. However, these plants were responsible for more than 70% of energy-sector emissions in 2010 (Foster and Bedrosyan, 2014). About half of these emissions are associated with combustion, mainly in power plants and refineries (IPCC, 2006). But at the same time, energy production plays a central role in economic and social development. This production affects health, well-being, food security, access to water, and agricultural productivity.

This paper explores the nexus between unconventional oil extraction techniques, air quality and economic development, with special emphasis on the case of Alberta (Canada). To explore this, preliminary statistical evidence is assembled into an original data-set. The sustainability of energy production is a controversial issue in Alberta because Canada is the only developed country that decided to withdraw from the Kyoto Protocol in 2011. It hosts the world's third-largest oil reserve after Saudi-Arabia and Venezuela.[1] The reason[2] behind Canada's withdrawal from Kyoto was its projected emissions increase, brought about by intensified production of its oil sands (Environment Canada, 2011, 2012). Following background analysis of the oil sands, the paper introduces the *Sustainable Income Index* (SII), an original index which features both an economic and environmental dimension. The purpose of the index is to offer a comprehensive perspective on country well-being, taking into account crude economic and environmental dimensions. The introduction of a measure of air quality counterbalances the negative externality generated by GDP. Alberta's SII is compared with selected countries, and a brief discussion concludes the paper.

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[1] The Alberta oil sands deposit is the world's third largest proven reserve of oil.
[2] For details see http://unfccc.int/files/kyoto_protocol/background/application/pdf/canada.pdf.

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2. What are oil sands?

Canadian oil sands are a mixture of sand, clay, water and bitumen, an extra-heavy crude oil that is highly dense and viscous. This oil is converted into a synthetic crude oil (SCO) trough separation from the other components of the sands and the following upgrading process.

Oil sands are found in approximately 70 countries (as commented in Alberta Geological Survey website), and Canada hosts the third-largest oil recoverable reserve in the world with a registered total production of 1,617,600 bbl/d of crude bitumen on 2011 (Alberta Government, 2012). This rate represents 73% of Alberta's total crude oil and equivalent production.

IEA estimates Canada's oil reserves capacity to be approximately 174 billion barrels. Of this total, 170 billion barrels are located in Alberta, of which approximately 169 billion barrels are composed of bitumen. Crude bitumen production, therefore, exceeds conventional crude oil in the area, accounting for 14% of global reserves (O and GJ, 2004).

Bitumen sand sites are located below a surface of 14 million ha (140,000 km^2). There are three major bitumen sand sites in northeast Alberta. Used areas under lease from the Central Government account for 9.3 million ha, or 66% of total area (see Table 1 for details). The largest area is the Athabasca, which is 9.3 million ha (66% of total area), of which 66% is under lease. This area is located in the province's northeast region, in the Regional Municipality of Wood Buffalo, and it has a population of 116,407 (Wood Buffalo 2012 Census).[3] Peace River hosts the second-largest deposit, with 2.9 million ha (21% of total oil sands area), of which 44% under lease. The main city center of Peace River contains 6,744 residents (Peace River 2012 Census), and is located in northwest-central Alberta. Cold Lake hosts the smallest deposit. This area has a surface of 1.8 million ha (13% of total oil sands), of which 52% are under lease (Alberta's Oil Sands Leased Area 2013). Cold Lake is the main city, with a population of 14,400 (Cold Lake 2012 Census).

Oil sands are important for the Canadian Government. According the Alberta Energy's Annual Report 2013/2014, royalties from synthetic crude oil and bitumen are the main source of revenue in Alberta, accounting for CAN$ 5.2 billion in royalties in the 2013–2014 fiscal year However, bitumen extraction also results in mass deforestation of Canadian boreal forest and a consequent loss of biodiversity. Extraction processes also release pollutants (CO_2, CH_4 and N_2O) into the atmosphere, and large amounts of water are consumed to separate bitumen from the mixture. Waste, or toxic mixtures of water, sand, silt, clay, chemicals, arsenic, mercury and hydrocarbons, is disposed of in tailings ponds. Because of its toxicity, this waste difficult to dispose of and typically left in the area of extraction. Environmental damage is also caused by pipelines carrying gas, roads transporting workers and machinery carrying finished products to mining sites.

Tar sand extraction is a matter of growing international concern because it affects ecosystem and human health (Timoney and Lee, 2009). Research has investigated air and water toxicity as a consequence of bitumen extraction. Several studies have undertaken life cycle assessments (LCAs) of oil sands technologies. These methods are useful for understanding the full impact of developing oil sands bitumen (i.e., from extraction of resources to disposal of unwanted residuals). Bergerson and Keith (2006) examines the application of LCAs to oil sands technologies, emphasizing public policy and methodological issues. Other studies have investigated the oil sands issue from the standpoint of environmental performance. McKellar et al. (2009) reviewed previous LCAs studies, comparing the environmental impact of liquid fuels produced from oil sands, conventional and other unconventional fossil fuel sources. Results showed that the oil sands pathways existing on a 'well-to-wheel' (WTW) basis generated 5–15% more GHG emissions than conventional crude oil.

Research has also been undertaken to ascertain the toxicity of tailing pods and to identify disposal challenges. In a study on Athabasca oil sands region of Small et al. (2015), it is suggested that the current tailings footprint (including water, sand beaches, dykes, and toe berms) is approximately 176 km^2. A large amount of boreal forest has been destroyed because of mining operations. The forest has also been polluted by waste from extractive activities that is acutely toxic to aquatic organisms and mammals. Hilson (2000) discussed the importance of implementing cleaner technologies and production practices in the mining industry and suggests that three major barriers preventing their implementation, namely economic, technological and legislative.

Other research has highlighted economic benefits, such as employment, public revenues and taxation. This body of research suggests that the oil sands deposits of northeastern Alberta are some of the few reliable long-term sources of crude oil (e.g., Giesy et al., 2010; CERI, 2011). Oil sands are extensive in size and found in a specific area in the boreal forest. This peculiarity allows for an early estimation of the volume of oil in place. The unconventional nature of oil sands also permits early sunk exploration costs.

Modularization has proved to be a key construction strategy in implementing Alberta oil and gas projects. Recently, Ikpe et al. (2015) reviewed literature on modularization, recognizing the uniqueness of heavy industrial projects in Alberta. These projects are often characterized by remoteness and climate challenges.

3. Extraction methods in a nutshell

"Open pit mining" is popular among large operators (e.g., Suncor and Syncrude), while "in situ processes" typically appeal to those companies engaged in smaller projects. Oil sands projects differ in scale, depending on their reservoir characteristics and the technology they deploy to extract (Charpentier et al., 2009). Shallow oil sands reserves are more readily and efficiently extracted by open-pit methods than deeper oil sands reserves, which are typically worked using in situ methods (Bergerson and Keith, 2006).

The open-pit mining process seen in Alberta is similar to those which are used in coal mining operations. They are used when bitumen is close to the surface. The mining site is cleared of trees, brush, and overburdened material above the oil sands layer, which made up of rocks, sand and clay material, by trucks and shovels. The upgrading process occurs when bitumen is converted into SCO. The in situ process features when bitumen deposits are located deep within the ground. The cyclic steam stimulation (CSS) and the steam assisted gravity drainage (SAGD) are the in situ techniques most commonly used in commercial projects.

Table 1
Alberta oil sands area and public revenue from leasing area.

Alberta oil sands area	Athabasca	Cold Lake	Peace River
Oil sands surface (Mha)	9.3	1.8	2.9
Surface in use (under lease)	66%	13%	21%
Main population city	Wood Buffalo	Cold Lake	Peace River
Population	116,407	14,400	6744

Sources: Wood Buffalo 2012 Census; Cold Lake 2012 Census; Peace River 2012 Census, Source Mapping & Analysis (JS), data provided by Spatial Data Warehouse. Alberta Energy, February 2014.

[3] There is a fourth deposit, Wabasca.

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