nature climate change

LETTERS

PUBLISHED ONLINE: 10 AUGUST 2014 | DOI: 10.1038/NCLIMATE2335

Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions

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Climate policy and analysis often focus on energy production and consumption[1,2], but seldom consider how energy transportation infrastructure shapes energy systems[3]. US President Obama has recently brought these issues to the fore, stating that he would only approve the Keystone XL pipeline, connecting Canadian oil sands with US refineries and ports, if it 'does not significantly exacerbate the problem of carbon pollution'[4]. Here, we apply a simple model to understand the implications of the pipeline for greenhouse gas emissions as a function of any resulting increase in oil sands production. We find that for every barrel of increased production, global oil consumption would increase 0.6 barrels owing to the incremental decrease in global oil prices. As a result, and depending on the extent to which the pipeline leads to greater oil sands production, the net annual impact of Keystone XL could range from virtually none to 110 million tons CO_2 equivalent annually. This spread is four times wider than found by the US State Department (1–27 million tons CO_2e), who did not account for global oil market effects[5]. The approach used here, common in lifecycle analysis[6], could also be applied to other pending fossil fuel extraction and supply infrastructure.

Globally, the International Energy Agency projects that nearly \$700 billion per year will be invested in the upstream oil and gas sector over the next two decades[7]. The resulting infrastructure could contribute to carbon lock-in and further the problem of 'carbon entanglement'[8]. Accordingly, it is crucial to understand the implications of fuel supply infrastructure for future greenhouse gas (GHG) emissions[9]. Innovations such as extraction-based carbon accounting[10] have helped quantify the emissions associated with fossil fuel supply, not just consumption, as has traditionally been the focus. However, few analyses have quantified the incremental GHG emissions impact of new fossil fuel supply infrastructure.

Broadly speaking, construction of fuel supply infrastructure could result in several categories of GHG impacts, including emissions associated with project construction and operation[5]; 'lifecycle' emissions associated with fuel extraction, processing and transportation[5]; and emissions associated with increased fuel use and combustion, due to price effects[6], if the infrastructure increases global fuel supply. Furthermore, high-profile decisions such as the US government approval of Keystone XL could have indirect, political or structural effects, if they lead other decision-makers to reject new fossil fuel infrastructure on GHG grounds or, conversely, lead to a political backlash that inhibits other efforts to reduce emissions[11]. Although this last category may be the most significant, quantification is difficult and inherently speculative, so we do not further analyse it here.

The three categories of emissions impact can be reflected, sequentially, as:

$$\Delta\text{Emissions} = \text{Emissions}_{\text{const}} + \Delta\text{Production} * (\text{EF}_{\text{proj}} - \text{EF}_{\text{ref}}) + \Delta\text{Consumption} * \text{EF}_{\text{ref}} \quad (1)$$

where: $\text{Emissions}_{\text{const}}$ = Emissions associated with infrastructure construction and operation, in tonnes CO_2 equivalent (CO_2e); ΔProduction = Increase in production of fuel handled by infrastructure project; EF_{proj} = Emissions factor, per unit of fuel handled, lifecycle basis; EF_{ref} = Emissions factor, per unit of displaced, reference fuel, lifecycle basis; ΔConsumption = Increase in fuel consumption resulting from increased production.

Factoring out the increase in production from the second two terms of equation (1) yields:

$$\Delta\text{Emissions} = \text{Emissions}_{\text{const}} + \Delta\text{Production} * \left((\text{EF}_{\text{proj}} - \text{EF}_{\text{ref}}) + \left(\text{EF}_{\text{ref}} * \frac{\Delta\text{Consumption}}{\Delta\text{Production}} \right) \right) \quad (2)$$

For the Keystone XL pipeline, the State Department has estimated all terms in equation (2) except the final one, a ratio that expresses the extent to which expanding oil sands production may increase global oil consumption. This term, and the effect it embodies, has not received significant attention in discussions of Keystone XL (ref. 12), and is therefore the subject of this Letter.

Microeconomic theory provides the tools to examine the price effect of adding new production capacity to an existing market[13]. Our simple model simulates the interaction between global oil demand[14] and supply[15] for the year 2020, as depicted in Fig. 1.

Similar economic models have been used to analyse the oil market impact of other US policies—for example, for the proposed expansion of oil extraction from the Arctic National Wildlife Refuge[13], expanded production of US biofuels[6], or recent proposals for new coal export terminals that may open new markets for Powder River Basin coal that might otherwise be shut in[16].

For small shifts in supply (830,000 barrels per day (bpd) is less than 1% of global oil supply), and for which the supply and demand curves can be represented as linear, the ratio of increased consumption to increased production can be approximated as the elasticity of demand (E_d) divided by the difference between the elasticities of demand and supply (E_s; ref. 13):

$$\frac{\Delta\text{Consumption}}{\Delta\text{Production}} \cong \frac{E_d}{E_d - E_s} \quad (3)$$

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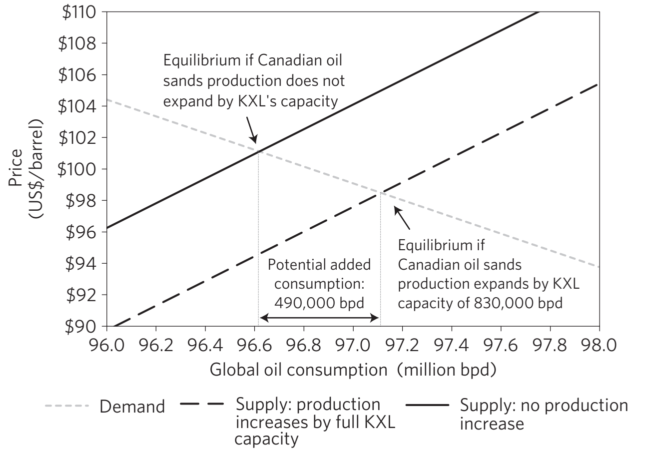

Figure 1 | Simple model of global supply and demand for oil: how increasing global oil supply via Keystone XL would decrease prices and increase consumption. We fix the demand curve, and adjust the supply curve to reflect the extent to which Keystone XL might affect Canadian oil sands production, from no effect to the full 830,000 bpd pipeline capacity.

Table 1 | Increase in annual crude oil consumption per barrel of added Canadian oil sands production under a range of demand and supply elasticities.

	Supply elasticity		
Demand elasticity	0.1	0.13	0.6
−0.054	0.35	0.29	0.08
−0.20	0.66	0.59	0.25
−0.36	0.78	0.73	0.38

Added consumption resulting from each unit of increased production ranges from 0.08 in the case of high supply and low demand elasticities to 0.78 in the case of low supply and high demand elasticities.

Using a long-run elasticity of supply of 0.13, as derived from a global oil supply curve for 2020[15] used by the International Energy Agency[7], and a long-run elasticity of demand of −0.20 from a literature survey[14], equation (3) results in an increase of 0.59 barrels of oil consumed for each barrel (bbl) of increased production. We use this ratio in equation (2); the value is similar to the market adjustment effect [0.5 (±0.2)] found in a recent modelling assessment of the impact of increased biofuel supply on global oil consumption[6].

To characterize uncertainties in the demand and supply relationships around the market-clearing price, we conduct a sensitivity analysis by varying demand elasticities by one standard deviation of values found in a literature survey[17] and supply elasticities across the values found in an OECD review[18], as shown in Table 1, and discussed further in the Methods section. In addition, there are a number of possible effects that our model does not capture—such as the increased availability of highly efficient vehicles, increased switching to non-petroleum transport fuels, or cartel behaviour among a small number of producers—although these effects, as noted in the Methods, are likely to be small.

For all other terms in equation (2), we use the State Department's findings. The GHG emissions impact of pipeline construction is minor, far less than 1 million tons CO_2e per year when spread over the pipeline's 50-year lifetime[5]. The GHG emissions of pipeline operation are similarly small, and slightly less than for alternative transport modes such as rail[19]. Because these net effects are small (less than 1 million tonnes CO_2e per year), we do not consider them further here.

The difference in lifecycle emissions between the oil sands and a reference crude may, however, be substantial. The State Department estimated the lifecycle emissions factor of oil sands ($EF_{proj} = EF_{oil\ sands} = 569$ kg CO_2e/bbl) to be 18% higher than that of the most likely alternative, reference crude, Middle Eastern Sour ($EF_{ref} = 481$ kg CO_2e/bbl). Equation (2) therefore suggests a GHG impact of 373 kg CO_2e [$(569-481)+481*0.59$] for each barrel of increased production. It remains possible that the reference crude could have a lifecycle GHG emissions intensity more similar to the oil sands. For example, the State Department provides one set of estimates for oil sands ($EF_{oil\ sands} = 557$ kg CO_2e/bbl) and a reference, Venezuelan crude ($EF_{ref} = 552$ kg CO_2e/bbl), that differ by only 1% (ref. 5). In this case, the increase in emissions from the substitution of oil sands for the reference crude would be less, but the emissions associated with increased global consumption would be greater, yielding 331 kg CO_2e [$(557-552)+552*0.59$] per barrel of increased production; 11% lower than if substituting for Middle Eastern Sour.

The overall GHG emissions impact of Keystone XL is determined, as shown in equation (2), by the extent to which Keystone XL leads to an increase in oil sands production. Here, the State Department concludes that owing to availability of other pipelines (for example, the proposed expansion of the Trans Mountain pipeline to Vancouver, British Columbia., or the proposed Northern Gateway pipeline to Kitimat, British Columbia) or rail for transporting oil sands crude, the rate of Canadian oil sands extraction would most likely be the same with or without Keystone XL (ΔProduction = 0), and therefore there is no GHG emissions impact. Other analysts suggest that the State Department may be overly optimistic, however, and that regulatory, environmental and local community barriers faced by other pipeline and rail options could ultimately restrict expansion of oil sands production[20,21].

The State Department also suggests a case in which the oil sands production could increase by Keystone's full capacity (ΔProduction = 830,000 bpd). If future oil prices are lower than expected, specifically $65–$75 per barrel, 'higher transportation costs (due to pipeline constraints) could have a substantial impact on oil sands production levels, possibly in excess of the capacity of the proposed Project'[5]. Oil prices could be lower than now forecast for a number of reasons. For example, technological progress in extraction and processing or the introduction of new low-cost supplies could increase competition among suppliers, shifting the supply curve to the right and lowering prices. Slower-than-expected growth in vehicle use in developing countries, or faster uptake of vehicle efficiency technologies, could shift the demand curve to the left, lowering prices. A combination of these and other factors could also present themselves, as in the US Energy Information Agency's (EIA) Low Oil Price projection, which falls within this range for nearly all of the next 20 years[22]. Furthermore, widespread implementation of GHG emission reduction policies would reduce demand for oil and, in turn, oil prices seen by producers, even though consumers might see higher prices under a carbon price[23–25].

The State Department calculates the GHG impact under the scenario where the Canadian oil sands production increases by the full amount of Keystone XL's capacity as 1.3–27.4 million tCO_2e per year, corresponding to the estimates of lifecycle emissions associated with oil sands relative to Venezuelan and Middle Eastern Sour reference crudes, respectively, as discussed above, and assuming perfect substitution of one fuel for another[5]. Using those same lifecycle emissions estimates and assumptions about increased oil sands production, our analysis suggests incremental GHG emissions of 100–110 Mt CO_2e, or four times the upper State Department estimate. The sole reason for this difference is that we account for the changes in global oil consumption resulting from increasing oil sands production levels, whereas the State Department does not. (We include results for all supply and demand elasticities considered, assuming a reference Middle Eastern Sour crude, in the Supplementary Information).

To put the scale of potential emissions increases from Keystone XL in context, consider that projected emission decreases in 2020 due to various US government climate policies under consideration are estimated to range from 20 to 60 Mt CO_2e for performance standards on industrial boilers, cement kilns and petroleum refiners (combined), and from 160 to 575 Mt CO_2e for performance standards on new and existing power plants[26].

Our simple model shows that, to the extent that Keystone XL leads to greater oil sands production, the pipeline's effect on oil prices could substantially increase its total GHG impact. Similar models are common in the lifecycle analysis literature. Methodological reviews have emphasized the importance of considering market-mediated effects in policy assessments, including in oil markets, and warned against the practice employed by the State Department of assuming perfect substitution of one fuel for another with no consideration of price and scale effects[27,28].

We see no indication that the State Department has considered these market effects in its assessment. The proprietary model it uses (EnSys' WORLD model)[5,29] is opaque with respect to key assumptions and features, such as global oil market response to changes in supply. By contrast, advantages of our simple model—using publicly available supply curves and peer-reviewed elasticities—are transparency and the ability to gauge the magnitude of possible price effects. Similar approaches could also be applied to other pending investments in fossil fuel extraction and supply infrastructure, such as deepwater oil rigs, new ports or rail lines to transport coal, or any of a host of investments under consideration that would expand global fossil-fuel supply[9].

The question of whether Keystone XL will 'significantly exacerbate the problem of carbon pollution' hinges on how much the pipeline increases global oil supply and, through price effects, global oil consumption. This Letter offers no new insights on whether Keystone XL will ultimately enable higher oil sands production levels: there are diverse viewpoints on whether alternative transportation options can fully substitute for Keystone XL. Instead, this Letter focuses on price effects and finds that, to the extent that Keystone XL may increase global oil supply, the State Department's assessment has overlooked the pipeline's potentially most significant GHG impact: increasing oil consumption as the result of increasing supplies and lowering prices.

Methods

Our model of global oil supply and demand is based on the standard approach for supply and demand analysis, for example as outlined by Perloff[13].

We draw our global oil supply curve for 2020 from the work of Rystad Energy[15]. Similar to other oil supply curves[30,31], Rystad's curve starts with significant conventional oil production in lower-cost regions (such as the Middle East), followed by a more steeply rising segment of higher-cost, less conventional resources (such as deepwater, enhanced recovery, oil sands) that represent the marginal resource. For example, Rystad's curve shows the cost of oil supply in 2020 rising sharply after 90 million barrels per day (mbpd). At the assumed equilibrium consumption level of 96.62 mbpd in 2020, per the US EIA (ref. 22), the real oil price is $101 US$/barrel and the elasticity of supply is 0.13. (See Appendix 1 in the Supplementary Information for the full cost curve.) For simplicity, we assume that Rystad's cost curve does not already include the oil to be carried by Keystone XL. If it did already include it, we estimate that the elasticity of supply at the equilibrium consumption level would instead be 0.11.

To model a demand response, we use the results of a literature review that estimates a long-run demand elasticity of −0.2 (ref. 14) which we use to approximate a demand curve that intersects the supply curve at the equilibrium consumption level noted above.

Assuming small changes in supply, a change in consumption can be estimated as the shift in the supply curve (change in production) multiplied by the elasticity of demand divided by the difference between the elasticities of demand and supply, $E_d/(E_d - E_s)$ (ref. 13).

Demand elasticities tend to be greater in the longer term than in the shorter term[14], as there is more time to invest capital in alternatives such as biofuels or high-efficiency or electric vehicles. Uncertainties also exist on the supply side. Technological progress in oil extraction and processing could flatten the curve, increasing the price elasticity of supply. (The elasticity of supply could also be lower if overall demand was less, and hence the equilibrium price was lower). Alternatively, if depletion effects (whether in conventional or unconventional sources) are stronger than assumed by industry analysts, the curve could steepen, decreasing the elasticity of supply. To characterize these uncertainties, we also consider a range of supply and demand elasticities. For demand elasticities we use a range from one of the studies cited by the literature review we use for our central estimate[17]. For supply elasticities, we use a range reported by the Organization for Economic Cooperation and Development[18].

We do not consider substitution or market effects with other fuels because most oil is consumed in the transport sector, where few alternatives are currently available and where the literature on elasticities of substitution for the key alternative—biofuel—is sparse[32]. If this method were applied to other fossil fuels, however—for example, the expanded supply of coal, which in most sectors, such as power, competes directly with other fuels and energy sources such as natural gas or renewable energy—such substitution effects would need to be considered.

Last, this simple model may miss more complicated effects, such as cartel behaviour, in which a small number of producers may manipulate the oil supply and prices. However, our literature review and analysis of global oil price behaviour found little compelling evidence of effective cartel influence; in the case of recent price increases, we found that low demand price elasticity, low supply elasticity (or the 'failure of global production to increase'), and growing demand from emerging economies are the main determinants of price[14]. Just as underinvestment has tended to lead to price increases[33], investment in supply infrastructure will tend to lead to price decreases. Our simple model also misses any market, and consequent emissions, impact should increased oil sands production increase the supply and depress the prices of refining co-products such as petroleum coke, LPG, or electricity, increasing their consumption and substituting for lower or higher carbon fuels.

Received 30 January 2014; accepted 11 July 2014;
published online 10 August 2014

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Acknowledgements

The authors would like to thank R. Plevin, T. M. Power and D. S. Power for their review and comments, M. Davis for her editorial acumen, and K. Tempest for his timely research support.

Author contributions

P.E. and M.L. designed the research. P.E. designed and constructed the spreadsheet model. P.E. and M.L. analysed the results and wrote the paper.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to P.E.

Competing financial interests

The authors declare no competing financial interests.