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Potential solar energy use in the global petroleum sector

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ABSTRACT

We examine the potential for solar energy in global oil operations, including both extraction and transport ("upstream") and refining ("downstream"). Two open-source oil-sector GHG models are applied to a set of 83 representative global oil fields and 75 refinery crude oil streams (representing ~25% of global production). Results from these models are used to estimate per-barrel energy intensities (power, heat), which are scaled to generate country-level demand for heat and power. Multiple solar resource quality cutoff criteria are used to determine which regions may profitably use solar. Potential solar thermal capacity ranges from 19 to 44 GW_{th} in upstream operations, and from 21 to 95 GW_{th} in downstream operations. Potential PV deployment ranges from 6 to 11 GW_e in upstream operations and 17–91 GW_e in downstream operations. The ranges above are due to both per-bbl variation in energy intensity, as well as uncertainty in solar resource quality criteria. Potential solar deployment in upstream operations would displace a much smaller fraction of upstream energy use because a large fraction of global upstream energy use is are either offshore or in high latitude regions (e.g., Russia, Canada, Central Asia).

1. Introduction

Oil and natural gas supplied nearly 55% of global primary energy consumption in 2012 [1]. Supplying oil in required quantities requires a major industrial effort to produce 90 million barrels of hydrocarbons per day and process it for use in our cars, trucks, and airplanes. Similarly, enormous quantities of natural gas are produced and transported across continents, and increasingly over oceans as liquefied natural gas (LNG). While the oil and gas sector produces and sells energy products, it is also a large consumer of energy.

Given the need to reduce greenhouse gas (GHG) emissions from all sectors of the economy, oil and gas companies should be interested in reducing GHG footprints from energy use by their operations. Could solar energy – carried by heat, steam, or electricity – be used in significant amounts by the global oil and gas sector in the future? If so, what is the scale of possible demand for solar energy in oil and gas operations?

Some prior studies have examined the use of solar energy in oil and gas operations. Pinkse and van den Buuse [2] examined the adoption of photovoltaics (PV) by major international oil companies in a case study approach. Absi Halabi et al. [3] estimated future potential energy use in the oil and gas sector and examine the potential use of solar in oil production, including temperature and energy requirements for thermal uses such as heated separations and solvent regeneration. Another specific application is the use of PV for cathodic protection against corrosion in remote locations [4].

Perhaps most fruitfully, a number of papers [5–9] have explored the use of solar energy for steam generation for use in heavy oil recovery via thermal enhanced oil recovery (thermal EOR). These papers have shown a good match between the quality of solar steam and that demanded for thermal recovery processes. In particular, coupled reservoir and geomechanical studies have shown that intermittent steam injection does not adversely affect reservoir performance due to the large thermal inertia of reservoir rock-fluid systems [6,7,9].

Energy use in global hydrocarbon (HC) operations has been estimated by the International Oil and Gas Producers (IOGP) organization [10], and by the International Petroleum Industry Environmental Conservation Association (IPIECA) [11], an international environmental consortium for oil and gas operators.

IOGP produces a yearly environmental performance report [12], which includes data on air and water emissions as well as energy

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use. In 2014, IOGP companies were responsible for producing 2077 million tonnes of HCs, or about 29% of global HC production (~15.5 billion BOE) [12, p. 7]. IOGP estimated the energy use for all activities upstream of the refinery inlet for oil, and upstream of the city or facility gate for natural gas [12].

The IOGP-estimated energy intensity of HC production varies greatly by region (see Supporting Information (SI) Table S1). For example, the Middle East region only consumed 0.36 GJ of primary energy per tonne (t) of HC produced, while North America consumed almost 10 times this amount at 3.09 GJ/t HC. IOGP does not differentiate the type of energy consumed, but instead breaks down energy use by “on site” vs. “purchased” energy [12, p. 33]. Scaling each IOGP region's energy consumption term by the fraction of that region's production included in IOGP datasets, 2013 total global energy consumption would be 10.5 EJ of primary energy (see SI Table S1).

IPIECA [13–15] covers both upstream HC activities and refinery operations (see SI Table S2). The most recent IPIECA report includes data from 2009 [15, p. 2]. Summing upstream categories that align with IOGP results (“production/processing” and “pipelines”), total upstream consumption was 9.92 EJ in 2009 [15]. BP reported total HC production increases of 10.8% between 2009 and 2013 [16]. Therefore, extrapolating IPEICA results for 2013 would therefore estimate approximately 10.99 EJ consumed, or 4.6% larger than IOGP figures.

IPIECA also estimated refinery energy use. IPEICA estimated refinery consumption of 11.56 EJ in 2009 [15]. Extrapolating this figure by BP-estimated crude oil output growth (6.2% from 2009 to 2013) [16], results in 2013 refinery primary energy consumption of 12.3 EJ.

In summary, if we combine IOGP and IPEICA figures, global upstream energy consumption in the oil and gas sector in 2013 was approximately 10–11 EJ, while refining energy use was approximately 12–13 EJ. Since these quantities represent ≈4–4.5% of global primary energy consumption, the oil and gas sector clearly represents a large target opportunity for solar energy.

Expanding on this prior work, we perform in this paper a preliminary assessment of possible capacity for solar energy to supply the needs of the oil and gas sector (henceforth, we will use the term hydrocarbons, HCs, when referring to oil and gas broadly). Because no global datasets are available at the level of detail needed to model solar energy applications, we apply a statistics-based modeling approach that derives possible uses from a suite of open source models applied to 75 representative global oilfields.

We model petroleum operations to examine the breakdown of energy use within the industry into thermal and electrical requirements, which can best be supplied by solar thermal systems and solar photovoltaic systems, respectively. Using global solar resource database, we perform an overall assessment of possible use of solar thermal and solar photovoltaic power in oil production. In addition, we explore the uncertainty associated with modeled per-bbl intensities for upstream and refinery operations.

2. Methods

2.1. Bottom-up energy intensity of oil operations

In order to estimate potential for solar use in HC production, we performed bottom-up modeling of energy use in oil operations. We performed this bottom-up modeling because we felt that it provides better resolution on the potential uses of solar energy in oil and gas operations. Because sparse data are available on global gas processing and production practices, we focused this process on estimating energy use in producing and refining oil. Some of the modeled energy use that we calculated might also reasonably be allocated to the co-produced associated natural gas, which is produced along with many global oil operations.

2.1.1. Upstream oil energy intensity

Energy use at 83 global oil fields or sub-field regions was estimated using the Oil Production Greenhouse Gas Emissions Estimator (OPGEE) model [17,18]. The OPGEE model has been described extensively in prior studies, including a comparison to other oil sector emissions models [19] as well as detailed uncertainty analysis [20,21]. These data were collected for the Oil Climate Index project [22]. These 83 fields account for ≈26% of 2013 world crude plus condensate production in 2013 [23]. These fields are chosen to be representative of the global oil industry, including fields in all geographic locations (all major global producing regions), in all types of environments (e.g., onshore and offshore) and using all major production techniques (primary production, enhanced oil recovery, etc.). Some of these fields represent multiple zones of the same region or “play” (e.g. Eagle Ford field is represented by four zones). See SI Table S3 for field details.

OPGEE estimates the energy use for all key procedures in upstream operations, which include exploration, production & extraction, surface processing, maintenance, waste disposal and transportation to refineries [17,18]. Extensive OPGEE model documentation is available to the reader, and the model is available for free download and use from Stanford University servers [17].

The 83 modeled oilfields were classified into four types:

1. Onshore oil
2. Offshore oil
3. Oil produced using thermal EOR
4. Oil sands mined from near-surface bitumen deposits

For purposes of this classification, *in situ* thermally-produced bitumen from Canada was classified as “thermal EOR” while bitumen mining projects were classified as “oil sands” projects.

For each oil category, the average energy use of each oil type was determined using OPGEE model results (see Table S4). Additionally, percentiles of each consumption type were computed.

Supporting Information section S3 gives for the complete set of specific OPGEE model changes, including direct reporting of worksheets and cells in which OPGEE model settings were changed.

Stated simply, the following modeling choices were made:

- For onshore fields, the fraction of electricity generated onsite is set equal to 0%, in order that electricity demands are reported as electricity, rather than on-site consumed natural gas used to generate power.
- Where energy demand is thermal in nature (e.g., boilers, solvent regeneration) energy is assumed provided by natural gas.
- Where the energy need is as work or rotational motion of shafts (e.g., pumps, compressors) this work is assumed provided by electricity.
- For compression and refrigeration work of gas fractionation (demethanizer), we assume these processes are driven by natural gas turbines.
- Offshore fields modeled assuming all power provided by on-site simple gas turbines.

Example electricity intensity distributions across are presented in Fig. 1. Fig. 1 (left) shows electricity used in upstream production/lifting, while (right) shows surface processing and separations (right). See SI Table S4 for full OPGEE model statistical results, including mean, standard deviation, 5%ile, 25%ile, 50%ile 75%ile, and 95%ile values for four energy types and four classes of fields.

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