Fossil Fuel Atlas

Illustrating the threats of fossil fuel production —
A rapid threat identification methodology and platform

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Stockholm Environment Institute (SEI) is an international non-profit research and policy organization that tackles environment and development challenges. We connect science and decision-making to develop solutions for a sustainable future for all. Our approach is highly collaborative: stakeholder involvement is at the heart of our efforts to build capacity, strengthen institutions, and equip partners for the long term. Our work spans climate, water, air, and land-use issues, and integrates evidence and perspectives on governance, the economy, gender and human health. Across our eight centres in Europe, Asia, Africa and the Americas, we engage with policy processes, development action and business practice throughout the world.

The mission of Global Energy Monitor (GEM) is to develop and share information in support of the worldwide movement for clean energy. In a world confronting climate change, data that informs strategies and solutions is more important than ever. GEM studies the evolving international energy landscape, creating databases, reports, and interactive tools that enhance understanding. GEM is developing a comprehensive set of tools that allow users to zoom out for summaries and analysis at the regional or global scale, or zoom in for background and details on any element of the system — coal mine, nuclear power plant, wind farm, oil extraction field, fossil gas pipeline, or oil tanker. We believe that the data we gather should be accessible to everyone, as we believe that everyone is affected by the issues our work addresses.

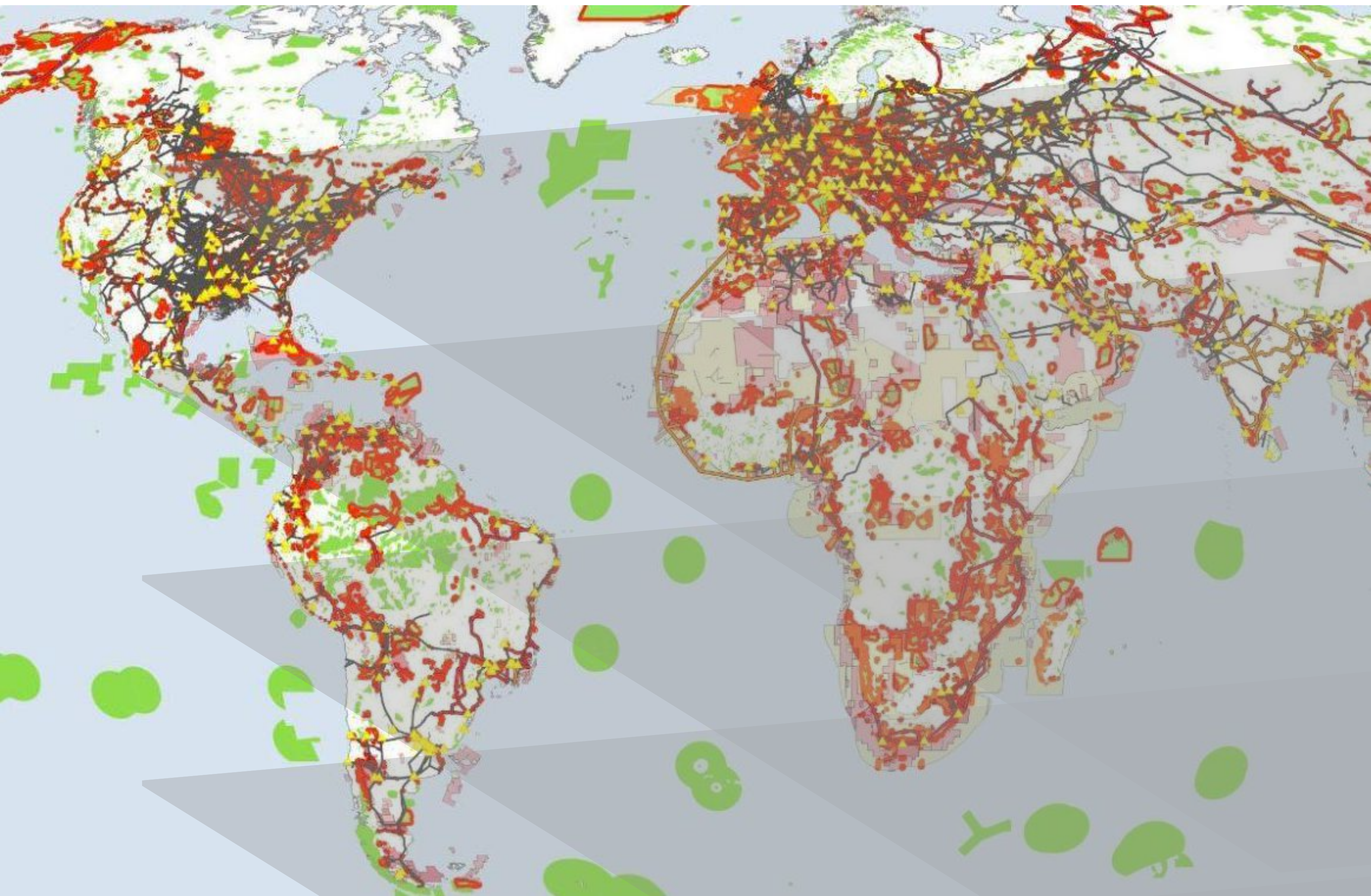
Institute for Governance and Sustainable Development (IGSD) works to promote just and sustainable societies and to protect the environment by advancing the understanding, development, and implementation of effective, and accountable systems of governance for sustainable development. IGSD has a range of projects in a variety of regions. Its members include practitioners and scholars from various developed and developing countries – including lawyers, political scientists, economists, scientists, and others – representing a diversity of geographic regions, and a wide range of cultural, legal, and political traditions.

Acknowledgements

SEI, GEM and IGSD conducted this research as part of a joint collaboration to create the Fossil Fuel Atlas, a data-driven transparency platform that allows users to visualize current and planned fossil fuel infrastructure, and how that infrastructure overlaps with protected areas, Indigenous territories, Ramsar protected wetland sites, and other areas of ecological and cultural importance. In view of the extent of the adverse social, climate and ecological threats of fossil fuel production, we have systematized an approach for creating rapid, scientifically grounded map visuals that make transparent the potential threats posed by prospective fossil fuel production projects. We thank the several other partners who provided feedback as we developed the methodology. Support for this research was provided by the Rockefeller Brothers Fund and IGSD.

Abstract

Fossil fuels account for over three-fourths of greenhouse gas emissions (IEA, 2021), fueling a climate crisis that is projected to devastate ecosystems and communities across the globe (IPCC, 2022; Rinawati et al., 2013). Fossil fuel production is already at a historic high, and is poised to continue growing (SEI and UNEP, 2021). Global fossil fuel production is known to have myriad adverse impacts on people and the environment (Butt et al., 2013). Many of the reserves targeted for extraction lie in highly sensitive ecological areas (Harfoot et al., 2018), with countless other upstream and midstream fossil fuel projects posing risks. In view of the extent of the adverse social, climate and ecological threats of fossil fuel production, we are promulgating a spatial mapping approach and accompanying open-access web platform (www.fossilfuelatlas.org) for creating scientifically grounded maps and other information-rich visuals that make transparent the threats posed by current and prospective fossil fuel production. In partnership, Stockholm Environment Institute (SEI), Global Energy Monitor (GEM) and the Institute for Governance and Sustainable Development (IGSD) are operationalizing this Geographic Information Systems (GIS)-based approach through a global open-access, on-line transparency platform, the Fossil Fuel Atlas, in collaboration with a growing community of stakeholders—including civil society organizations and decision-makers—who are addressing fossil fuel extraction at local to international scales.



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1. Introduction

Fossil fuels account for over three-fourths of greenhouse gas emissions (IEA, 2021), fueling a climate crisis that is projected to devastate ecosystems across the globe (IPCC, 2022; Rinawati et al., 2013). But their impact goes beyond the climate change caused by fossil fuel-related greenhouse gas emissions. The worldwide extraction and production system that delivers fossil fuels to end-users itself poses immediate threats to the ecosphere. Fossil fuel production systems — the sprawling networks of mines and wells, pipelines and refineries, roads, port facilities and other infrastructure that produces, transports and supplies fossil fuels to users — routinely degrade landscapes, release numerous pollutants into our land, water, and air, introduce light pollution and invasive species into ecosystems, and cause other forms of ecological deterioration (Butt et al., 2013). The impacts of fossil fuel extraction can compound, producing detrimental long-term outcomes (Yusta-García et al., 2017).

This threat is expanding. Fossil fuel extraction is already at a historic high, and is poised to continue growing (SEI and UNEP, 2021). In addition, many of the reserves targeted for extraction lie in highly sensitive ecological areas (Harfoot et al., 2018). Since an intact ecosphere provides ecosystem services that are essential for society to function (Díaz et al., 2006; Millennium Ecosystem Assessment, 2005), the significant planned expansion of fossil fuel extraction and production poses a global threat to humankind.

In view of the extent of the adverse social, climate and ecological threats of fossil fuel production, Stockholm Environment Institute, Global Energy Monitor, and Institute for Governance & Sustainable Development have developed a mapping approach and an accompanying open-access mapping platform for creating rapid, scientifically grounded map visuals that make transparent the threats posed by fossil fuel production. The flexible, intuitive mapping approach is quickly taught, and can be adapted by stakeholders based on their priorities and technical capacities.

This mapping approach is being used in collaboration and partnership with civil society organizations and networks with diverse priorities (e.g. biodiversity, climate change, human rights, water resources, etc.) and internal technical capacities. Simultaneously, we are developing Fossil Fuel Atlas' tools and resources in iterative, ongoing stakeholder feedback cycles. In doing so, the Fossil Fuel Atlas platform can be optimized so these resources can be freely accessed, and the mapping approach easily used, by the diverse stakeholders addressing fossil fuel extraction from local to international scales.

The fossil fuel system has various impacts beyond those described here (e.g. conflict - Acuña, 2015; political-economic - Satti et al., 2014). To keep the scope of work manageable, we focus on how extraction and production activities drive adverse ecological impacts and consequent social repercussions. The report is organized as follows. First, the paper summarizes the literature on empirical observations of a wide range of the ecological impacts caused by fossil fuel production, which includes a global overview of oil and gas extraction in order to demonstrate the threats that fossil fuels pose to our ecosphere (Section 2). It then expands upon the mapping approach in-depth and describes how it is being made accessible at scale via the Fossil Fuel Atlas mapping portal (Section 3), before offering several examples of maps created using this approach (Section 4). Section 5 concludes the paper.

Key terms

Fossil Fuel Production: refers to the supply chains, processes, and infrastructure that deliver fossil fuels to market for use as a fuel or feedstock (this includes extraction).

Fossil Fuel Extraction: one of the first steps in the fossil fuel production supply chain, whereby fuels are physically removed from the earth.

Ecological Integrity: the structure, function and composition of an ecosystem as compared to a reference state free of anthropogenic interference (Hansen et al., 2021).

Threats, Risks, and Impacts: here, we use these three terms on a continuum of potential (threats) to realized (impacts) harms.

Threats refer to the many potential adverse ecological or social consequences of fossil fuel production, ranging from the global effects from fossil fuel use broadly (e.g., climate change) to the localized effects that can accompany specific production activities (e.g. oil spills).

Risks refer to those specific adverse consequences – often probabilistically quantified based on accepted assessment methodologies – from a production project (e.g. risks to water resources from pipeline spills, or risks to biodiversity from ecosystem fragmentation).

Impacts refer here to the actual, realized consequences of extant fossil fuel production projects.

2. Overview of the social and environmental threats of fossil fuel production

Fossil fuels are driving the climate and ecological crises. Section 2.1 details how fossil fuels are driving these crises, summarizing previous literature (academic and grey) on the subject and honing in on the social and environmental impacts of fossil fuel production laid out in Table 1 and Table 2. Section 2.2 walks through a series of maps depicting global fossil fuel production and, as an introduction to the methodology and mapping portal described later in Section 3, illustrates some of the ways that fossil fuel production infrastructure threatens people and ecosystems.

2.1 Fossil Fuels: Driving the climate and ecological crises

Without the ecosystems and biodiversity that provides vital ecosystem services, human society could not exist (Millennium Ecosystem Assessment, 2005). Humans rely on ecosystems and biodiversity for raw materials, food security, water regulation and filtration, soil fertility, pollination, disease control, climate regulation, genetic resources, and much more (Díaz et al., 2006; Sandker et al., 2017; Schmeller et al., 2020; Turbé et al., 2010). These contributions are being degraded at an unprecedented rate by many human activities, which can be categorized into five primary drivers of ecological degradation: land/sea use change, direct exploitation, climate change, pollution, and invasive alien species (IPBES, 2019). Fossil fuel production and combustion contribute to all five primary drivers of ecological degradation—and it is the main cause of climate change, the driver poised to become the main source of ecological degradation and biodiversity loss (IPBES, 2019; IPCC, 2018; Urban, 2015).

Fossil fuels are responsible for 75% of the greenhouse gas emissions causing climate change (IEA, 2021). If warming exceeds 1.5°C above preindustrial levels, "the biology of the planet becomes gravely threatened because ecosystems literally begin to unravel" (Dinerstein et al., 2020; see also Rinawati et al., 2013). To avoid catastrophic levels of climate change and runaway ecological deterioration, society must break its dependence on fossil fuels (United Nations Environment Programme, 2022; Welsby et al., 2021). However, plans and projections for the next two decades would raise fossil fuel production to 120% over what is compatible with a 1.5°C world (Figure 1, red line) (SEI and UNEP, 2021). Since early 2020, G20 governments have committed at least 300 billion USD to fossil fuels by way of various policies (Energy Policy Tracker, 2021). The United States is projected to lead this coming decade's wave of expansion, boosting its annual production of both oil and gas by more than the combined increase of the remaining top fifteen producers (Achakulwisut & Erickson, 2021).

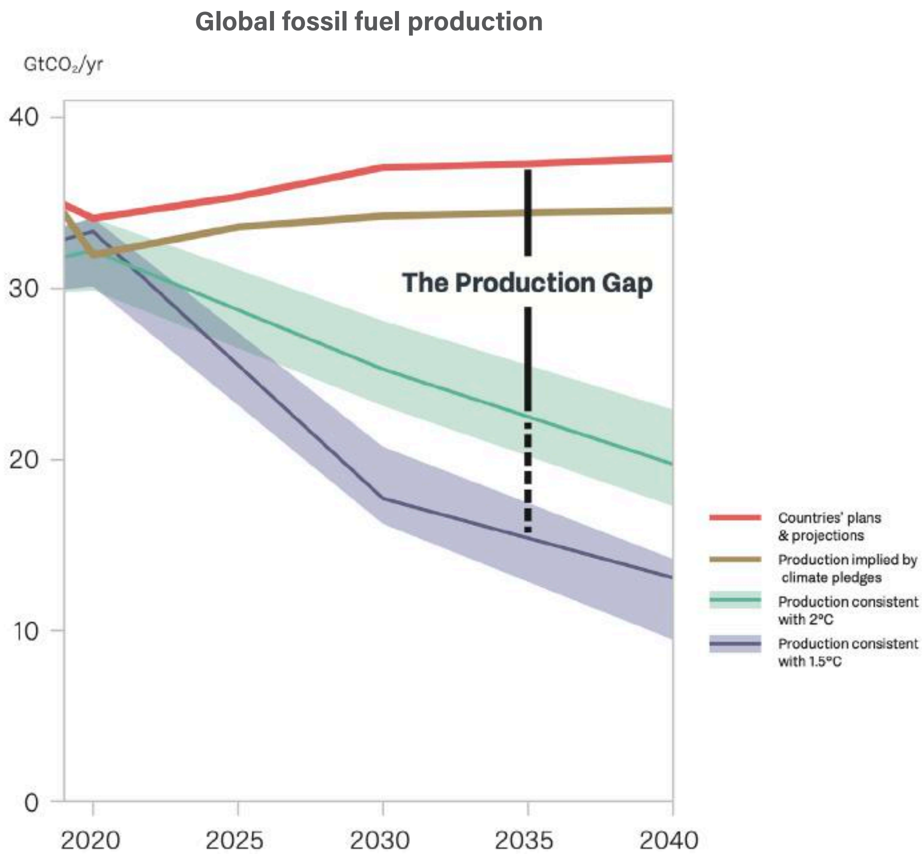


Figure 1. From (SEI and UNEP, 2021). Contrasts the continuing rise in global fossil fuel production based on plans and projections of countries and companies (red line) against the future production levels that would be consistent with keeping global warming below the temperature limits agreed by national governments and codified in the Paris Agreement (green and blue lines). The green and blue lines correspond to fossil fuel production consistent with keeping warming below 2°C and 1.5°C, respectively.

The aggregate ecological harms of fossil fuel production and global climate change could push some of these ecosystems past their ecological tipping points, opening a pandora's box of runaway ecosystem deterioration (IPBES, 2019; Lenton et al., 2019). Fossil fuel exploitation depends on an expanding global network of extraction and production infrastructure that poses numerous threats to the environment on which we all depend (Butt et al., 2013). In general, each additional fossil fuel project imposes a range of additional pressures and presents the threat of further impacts to ecosystems and communities (L. Allen et al., 2011; Epstein et al., 2011; Jernelöv, 2010; Rosa et al., 2017; Tustin et al., 2017; Vidic et al., 2013). The pressures imposed by fossil fuel activities on ecosystems are outlined in Tables 1, roughly disaggregated among those air, land, and water, and for these pressures, the range of potential impacts is briefly outlined. Table 2 presents the consequences that can in turn arise for human communities dependent on these ecosystems, roughly categorized among those occurring to: Indigenous and Communal Lands, Livelihoods, Water Quality, Water Availability, Health, Agriculture. Key sources are provided alongside each of these potential impacts and consequences.

It is important to note that these impacts do not operate in isolation, but interact in ways that are difficult to predict. When complex adaptive systems like ecosystems are perturbed by such pressures, they typically do not respond in a linear way (Simon A. Levin, 1998). The consequences can be seemingly disproportionate, cascading and often long-term. For example, habitat loss, toxic substance releases, and intensive water extraction commonly accompany fossil fuel production projects (Tables 1 and 2). Such activities have been shown to cause ecological degradation extending well beyond the production infrastructure's spatial and temporal footprint, permeating surrounding ecosystems and creating adverse impacts on communities for years to decades (Butt et al., 2013; Pegg & Zabbey, 2013; Yusta-García et al., 2017). Other pressures such as noise and light pollution, the impacts of which seem discrete and spatially isolated at first glance, can also produce long-term, cascading environmental repercussions (Bayne et al., 2008; Butt et al., 2013). Furthermore, fossil fuel production projects typically have more than one adverse impact on the environment. For example, the impacts of habitat fragmentation caused by road construction to a coal deposit compound with those caused by subsequent landscape alteration and toxic substance release upon extraction and transportation (Epstein et al., 2011).

These adverse ecological impacts take place in addition to the many other human activities driving ecological degradation and biodiversity loss (IPBES, 2019). Across the globe, key terrestrial and marine ecosystems and biomes are already approaching 'tipping points' after which ecological degradation and massive biodiversity loss is a scientific certainty (Lenton et al., 2019). For example, it could take as little as 3% more deforestation in the Amazon for it to reach its ecological tipping point, an alarming possibility which planned oil and gas expansion in the rainforest's central and western regions could easily bring about (id.).

Any of the threats and impacts in Table 1 has the potential to trigger trophic cascades (Ripple et al., 2016) or harm critical keystone species (Simon A. Levin, 1998), which tend have much larger aggregate consequences than the seemingly minor human interferences that trigger them (Butt et al., 2013). Given the potential for disproportionate and long-term impacts of fossil fuel activities, the sheer scale of its potential continued expansion is particularly concerning, especially in light of the degree to which remaining reserves are tied up in the world's remaining natural areas (Harfoot et al., 2018).

In the following sections, we describe and demonstrate the methodology for rapidly assessing the various threats of proposed fossil fuel extraction activities, from the global to the local levels.

Photo: Floods in Nigeria. Photo credit: Chinedu Chime

Pressures and threats to biodiversity and ecosystems posed by fossil fuel production (Table 1)

BIODIVERSITY AND ECOSYSTEM THREATS — LAND		
Deforestation **Land Conversion** **Fragmentation**	Fossil fuel exploration, construction, and other production processes often involve razing forest and vegetation cover to make room for infrastructure (Harfoot et al., 2018). This can adversely alter ecosystem species compositions, nutrient cycling, and the local water cycle (Seymour & Harris, 2019). Fragmentation, caused by construction of roads and pipelines, is an insidious form of landscape alteration that affects gene flow, habitat area, and even nutrient cycling and biomass storage (Dinerstein et al., 2019). The impacts of deforestation and fragmentation are particularly severe for the atypical fossil fuels like shale gas and tar sands mining, which tend to have expansive physical footprints (Gonzalez, 2016; Kuwayama et al., 2013; Rosa et al., 2017).	(Agbagwa & Ndukwu, 2014; Butt et al., 2013; Copeland et al., 2009; Dean et al., 2019; Dinerstein et al., 2019; Gonzalez, 2016; Haddad et al., 2015; Harfoot et al., 2018; Jones et al., 2015; Krauss et al., 2010; Kuwayama et al., 2013; Nasen et al., 2011; Rosa et al., 2017; Seymour & Harris, 2019; Zemp et al., 2017)
Invasive Species	Invasives transported into ecosystems during exploration, construction, and other steps in fossil fuel production can destroy native species, triggering cascades of repercussions that reduce ecosystem integrity and biodiversity. The soil disturbance and long-term vehicle traffic inherent to fossil fuel development increases the risk of invasive species for many years after construction is complete (Brooks, 2007; Preston, 2015).	(Brooks, 2007; Jones et al., 2015; Preston, 2015)

BIODIVERSITY AND ECOSYSTEM THREATS — WATER		
Inland Oil Spills **Marine & Coastal Spills** **Small Oil Spills**	Pipeline spills can propagate over large distances by rivers and streams, and it can spread in groundwater for years without discovery (Kammoun et al., 2020). When oil releases over land infiltrate surface and groundwater, it can lead to adverse impacts on flora and fauna that last for decades to centuries (Manshoori, 2011). Oil spills in marine ecosystems, especially in sensitive coastal, estuarine and mangrove ecosystems, can cause long-term and even permanent ecological damage (Moreno et al., 2013; Zabbey & Olsson, 2017). When oil spills permeate mangroves, the root system dies and the mud that supported them is washed out to sea, making restoration incredibly difficult (Jernelöv, 2010). The impacts of chronic small oil spills, which are ubiquitous offshore and onshore but rarely receive attention, are at least as devastating for ecosystems as large spills (Redondo & Platonov, 2009).	(Haddad et al., 2015; Jernelöv, 2010; Kammoun et al., 2020; Manshoori, 2011; Moreno et al., 2013; Nelson & Grubesic, 2018; Redondo & Platonov, 2009; Snowden & Ekweozor, 1987; Zabbey &

Table 1: Pressures and threats to biodiversity and ecosystems posed by fossil fuel production

BIODIVERSITY AND ECOSYSTEM THREATS — WATER		
Water Contamination	Conventional oil, gas, and coal extraction all release enormous volumes of produced water, a liquid that typically contains hydrogen sulfide, hydrocarbon residues, various heavy metals, and high concentrations of salts (Yusta-García et al., 2017). Tar sands and coal mining both produce tailings, a liquid containing hydrocarbons, heavy metals, arsenic, and other toxic substances (L. Allen et al., 2011). Even when properly disposed of in open 'tailing ponds,' they adversely impact ecosystems from both direct contact and leaching into surface and groundwater (Jordaan, 2012; Kuwayama et al., 2013). Solid waste from both shale oil and coal mining—surface and underground alike—are known to poison water supplies: for example, ninety four percent of carcinogens released during coal production are emitted to water, posing immense threats to exposed ecosystems (L. Allen et al., 2011; Epstein et al., 2011).	(L. Allen et al., 2011; Epstein et al., 2011; Jordaan, 2012; Kuwayama et al., 2013; Vidic et al., 2013; Yusta-García et al., 2017)
Water Consumption	The water footprint of fossil fuel production can be extensive (Jordaan, 2012). Up to seven million gallons of water are extracted to drill a single conventional oil or gas well (Jones et al., 2015), and unconventional fossil fuel production (e.g. tar sands and shale gas extraction) can have even greater impacts on water availability for ecosystems (Kuwayama et al., 2015).	(L. Allen et al., 2011; Jones et al., 2015; Jordaan, 2012; Kuwayama et al., 2013, 2015; Rosa et al., 2018)

BIODIVERSITY AND ECOSYSTEM THREATS — AIR		
Air Pollutants	Air pollutants from fossil fuel production such as nitrogen oxides, sulfur dioxides, and VOC's adversely impact ecosystems in many ways. Gas flaring across the Niger Delta induced acid rain that destroyed forests and led to biodiversity loss (Ejiba et al., 2016). Other sources, including unconventional oil and gas, conventional fuel extraction, and oil refineries release a whole host of air pollutants that damage proximal ecosystems (D. T. Allen, 2016; Hitaj et al., 2020). Air also contains a vast array of biological information in the form of chemical messengers, temperature, and humidity, changes in which can build on the myriad other ecological impacts of fossil fuel production.	(D. T. Allen, 2016; Alshahri & El-Taher, 2018; Bamberger & Oswald, 2014; DeLuchi, 1993; Ejiba et al., 2016; Hitaj et al., 2014, 2020; Jung et al., 2013; Rajabi et al., 2020)
Noise and Light Pollution	Vehicle traffic, drilling rigs, fracking operations, freighters, flare stacks, generators, landscape conversion, and mining operations are some of the many sources of noise and light pollution accompanying fossil fuel production (Jones et al., 2015). The changes in species' behavior, population sizes and habitat preferences caused by noise pollution can have cascading impacts that degrade ecosystem integrity and biodiversity in marine and inland environments alike (Bayne et al., 2008).	(Barber et al., 2011; Bayne et al., 2008; Brooks, 2007; Dean et al., 2019; Jones et al., 2015)

Table 1: Pressures and threats to biodiversity and ecosystems posed by fossil fuel production (continued)

Environmentally mediated social threats and impacts of fossil fuel production (Table 2)

SOCIAL THREATS AND IMPACTS:		
Indigenous and Communal Lands	Fossil fuel extraction and production often bypasses explicit and traditional indigenous land rights (Temper, 2019). The destruction of nature in these areas can cause all of the impacts described below, but it can also be a form of cultural dispossession, as well as a mode of dispossession of indigenous identities (Acuña, 2015). Protests against the destruction wrought by fossil fuel production are often met with corporate and state-sponsored violence against indigenous peoples (Muttitt & Kartha, 2020). Additionally, formally and traditionally recognized indigenous lands are often ecologically rich and contain at least 22% (217,991 MtC) of global forest carbon (Rights and Resources Initiative, 2018).	(Acuña, 2015; Jonasson et al., 2019; Kraushaar-Friesen & Busch, 2020; Murrey, 2015; Muttitt & Kartha, 2020; Rights and Resources Initiative, 2018; Temper, 2019)
Livelihoods	Approximately 2.5 billion people depend on healthy forests and other types of ecosystem for their livelihoods (Rights and Resources Initiative, 2018). Oil spills can decimate fish populations, undermining fishing for subsistence ; deforestation and fragmentation can drive away game for hunting and eliminate plants used for medicine and food; and the modification of the local landscape can damage important sources of culture and identity (Ejiba et al., 2016; Manshoori, 2011). As with their ecological counterparts, these impacts often produce long-term consequences such as parents not being able to afford to send their children to school due to economic losses from fossil fuel production's impacts (Pegg & Zabbey, 2013).	(Ejiba et al., 2016; Haddad et al., 2015; Manshoori, 2011; Pegg & Zabbey, 2013; Rights and Resources Initiative, 2018)
Water Quality and Availability	The depletion of water resources for fossil fuel extraction has adverse impacts on nearby communities. Approximately 31-44% of unexploited oil and gas deposits lie in areas of water stress or areas that would become water stressed with fossil fuel extraction (Rosa et al., 2018). Water use for coal and unconventional fossil fuel production can also limit water availability, threatening nearby communities that depend on reliable sources of freshwater and the ecosystems supported by that water (Epstein et al., 2011; Kuwayama et al., 2015; Rosa et al., 2017, 2018). Landscape alteration from fossil fuel production, as well as the release of oil, produced water, tailings, and other substances, can degrade water quality with commensurate impacts on human health (L. Allen et al., 2011).	(D. T. Allen, 2016; Ejiba et al., 2016; Epstein et al., 2011; Haddad et al., 2015; Jones et al., 2015; Kuwayama et al., 2015; Manshoori, 2011; Pegg & Zabbey, 2013; Rosa et al., 2017, 2018; Yusta-García et al., 2017)

Table 2: Environmentally mediated social threats and impacts of fossil fuel production

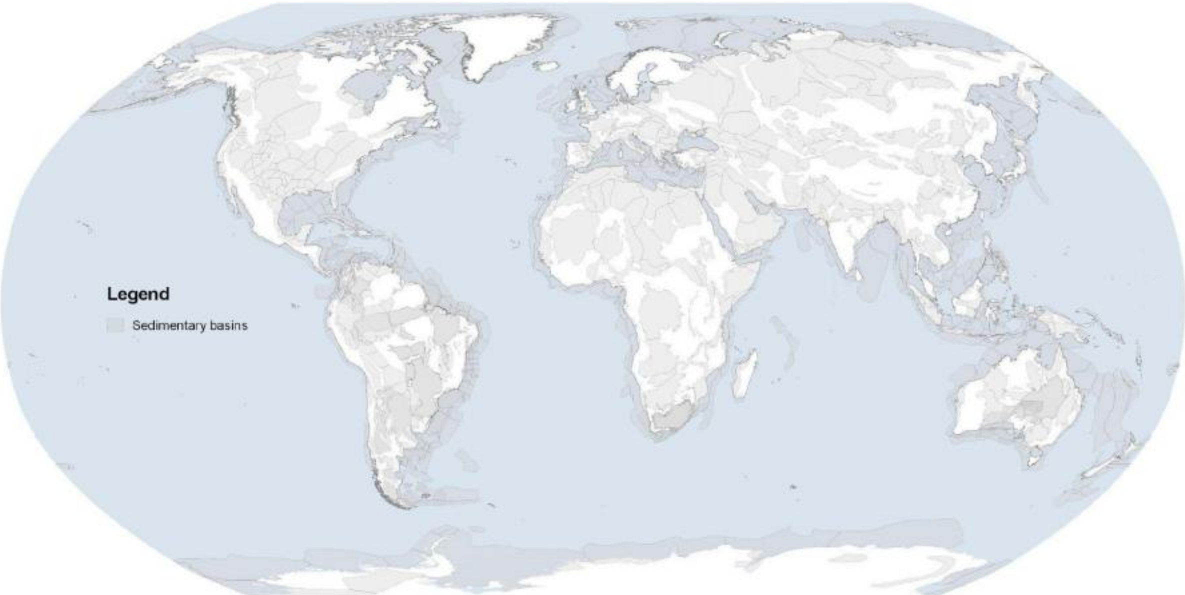
SOCIAL THREATS AND IMPACTS		
Health	Fossil fuel production can lead to acute and chronic exposure to arsenic, heavy metals, and other contaminants that degrade human health. Fossil fuel production increases the risk of cancer-related mortality and a variety of health conditions caused by exposure via air or consumption of water, plants, animals products contaminated with oil, produced water, and other wastes (L. Allen et al., 2011; Epstein et al., 2011). Exposure to both oil spills and pollution from oil refineries has been shown to increase the prevalence of respiratory problems, abortions, skin diseases, cancers, and self-perceptions of poor health (Khatatbeh et al., 2020; Manshoori, 2011). Were a large oil spill to enter a major freshwater source (such as Lake Victoria, which supplies water for 30 million people) the consequences for human health would be catastrophic. Simply living near a coal mine has been shown to cause preterm birth and birth defects, decrease scores on neurological tests, worsen diabetes, and increase mortality from heart, respiratory, and kidney disease, lung cancer (Epstein et al., 2011). As with the impacts of fossil fuel production on agriculture, health impacts can have further consequences for the livelihoods of those directly exposed as well as for their offspring and wider community (Bruederle & Hodler, 2017; Karadžinska-Bislimovska et al., 2010; Khatatbeh et al., 2020).	(Abbas et al., 2010; Adgate et al., 2014; Bruederle & Hodler, 2017; Epstein et al., 2011; Johnston et al., 2019; Karadžinska-Bislimovska et al., 2010; Khatatbeh et al., 2020; Manshoori, 2011; Wilke & Freeman, 2017)
Agriculture	Billions of people depend on agriculture for subsistence and income. Oil spills, air pollutants, produced water, and invasive species (to name but a few) poison crops and reduce overall yields (Ejiba et al., 2016; Pegg & Zabbey, 2013). Oil and liquid pollution infiltrate agricultural soils, reducing their technical efficiency for many years, and invasive species can make growing native crops virtually impossible (Ejiba et al., 2016).	(Abbas et al., 2010; Ejiba et al., 2016; Hitaj et al., 2014; Manshoori, 2011; Measham et al., 2016; Pegg & Zabbey, 2013)

Table 2: Environmentally mediated social threats and impacts of fossil fuel production (continued)

2.2 *Mapping the threats of oil and gas production*

This subsection provides a map-based introduction to global fossil fuel production and then demonstrates how nominally public datasets pertaining to people, the environment, and fossil fuels can be combined to illustrate the global threat of fossil fuel production described in Section 2.

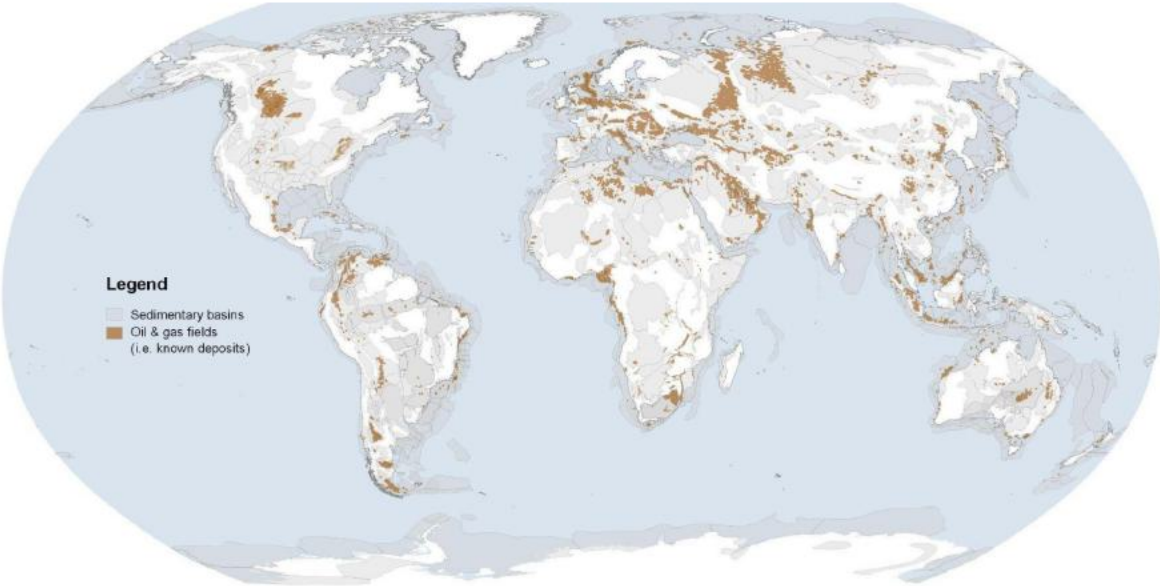
Fossil fuels exploration and extraction take place in geological formations called sedimentary basins. Figure 2 below shows the locations of earth's sedimentary basins in gray (notice that these basins exist both onshore and offshore).



Oil & gas basins from the Global Oil & Gas Infrastructure (GOGI) database, 2022: Sabbatino, M., Romeo, L., Baker, V., Bauer, J., Barkhurst, A., Bean, A., DiGiulio, J., Jones, K., Jones, T.J., Justman, D., Miller III, R., Rose, K., and Tong., A., Global Oil & Gas Infrastructure Features Database Geocube Collection, 2019-03-25, https://edx.netl.doe.gov/dataset/global-oil-gas-infrastructure-features-database-geocube-collection, DOI: 10.18141/1502839

Figure 2. Earth's sedimentary basins. Sedimentary basins are areas of earth's crust where organic material and sediment have collected and compacted over millions of years, sometimes in conditions that form hydrocarbon deposits.

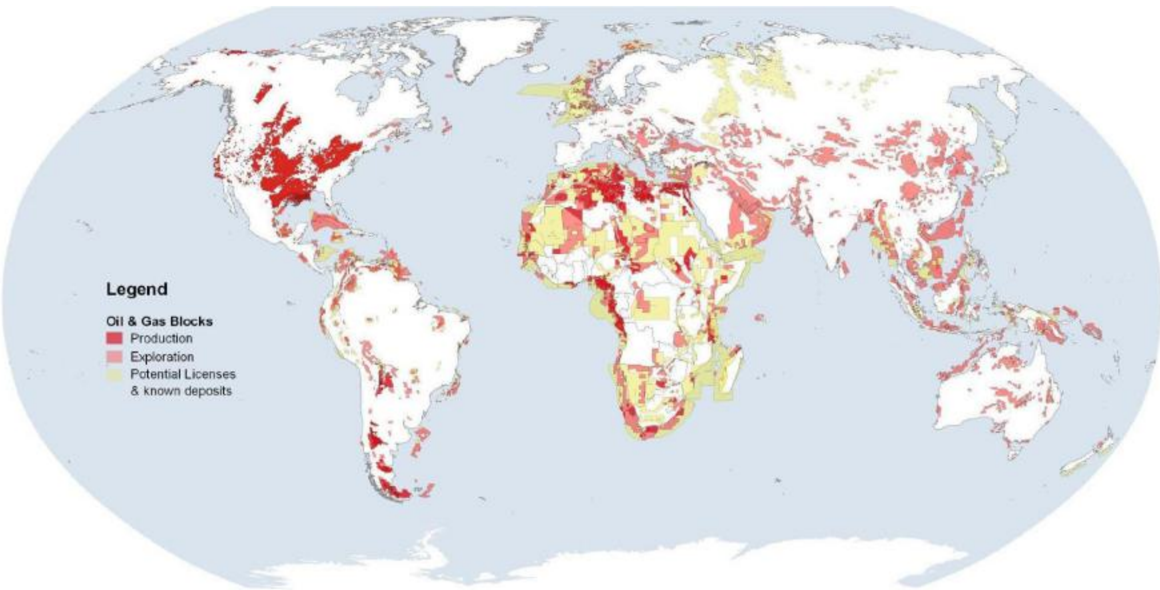
Oil and gas fields are the areas within these sedimentary basins where fossil fuel reserves have been identified. Figure 3 shows the locations of known oil and gas fields.



Data from the Global Oil & Gas Infrastructure (GOGI) database, 2022: Sabbatino, M., Romeo, L., Baker, V., Bauer, J., Barkhurst, A., Bean, A., DiGiulio, J., Jones, K., Jones, T.J., Justman, D., Miller III, R., Rose, K., and Tong., A., Global Oil & Gas Infrastructure Features Database Geocube Collection, 2019-03-25, https://edx.netl.doe.gov/dataset/global-oil-gas-infrastructure-features-database-geocube-collection, DOI: 10.18141/1502839

Figure 3. Sedimentary basins and oil and gas fields (i.e. known fossil fuel deposits).

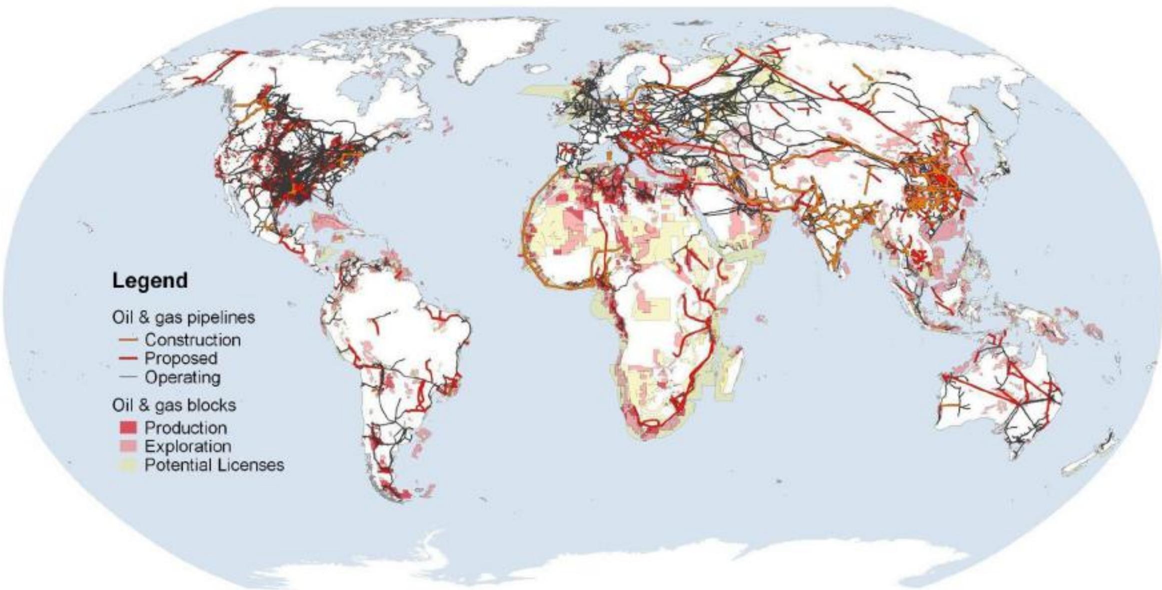
In order to access these known deposits and/or search for new ones, production companies purchase oil and gas concessions (commonly referred to as oil and gas blocks) that grant them rights to use a certain area for fossil fuel exploration or production. These concessions typically grant companies either exploration rights (searching for new fields or collecting more information on existing ones) or production rights (extracting the reserves). Figure 4 shows the global oil and gas blocks dataset that we are developing.



NOTE: While most shapes on the map do indicate the physically licensed area (or potentially licensed area), we have used oil and gas fields as a proxy for the location of potential licenses in eastern Europe/western Russia and active oil/gas wells as a proxy for licensed areas in the United States (data from GOGI database in both cases, see reference below).
Data accessed from a variety of sources including www.oilmap.xyz, WWF SIGHT public data (coordinates only), digitizing and cross-referencing with static maps, and from the Global Oil & Gas Infrastructure (GOGI) database, 2022: Sabbatino, M., Romeo, L., Baker, V., Bauer, J., Barkhurst, A., Bean, A., DiGiulio, J., Jones, K., Jones, T.J., Justman, D., Miller III, R., Rose, K., and Tong., A., Global Oil & Gas Infrastructure Features Database Geocube Collection, 2019-03-25, https://edx.netl.doe.gov/dataset/global-oil-gas-infrastructure-features-database-geocube-collection, DOI: 10.18141/1502839

Figure 4. Oil and gas concessions, also known as lease blocks. Fossil fuel companies are typically granted production rights (dark red) or exploration rights (light red) in these areas for a fixed period of time. Governments routinely auction currently unlicensed blocks (yellow) as new fields are found or changing economic conditions make known deposits economically viable. Based on available data — see note at base of map.

When an oil or gas deposit is found in one of these basins, plans to construct extraction and transportation infrastructure quickly follow. Over 1.1 million km of major pipeline, shown below in Figure 5, currently transport fossil fuel reserves from extraction sites to downstream production facilities (Global Energy Monitor, 2021).



NOTE: Active wells are used as a proxy for production areas in North America. Yellow shapes represent potential licenses in most cases. In eastern Europe and western Russia, however, yellow shapes indicate only known oil and gas fields. We are still consolidating data on oil and gas blocks globally, but particularly in this area. Oil and gas pipelines from Global Energy Monitor's GFIT Tracker (2022). Oil and gas block data assembled as part of the Fossil Fuel Transparency Initiative.

Figure 5. Pipelines and oil and gas blocks. The United States, Europe, and the Middle East, which have been areas of intensive oil and gas production for decades, are densely networked with existing pipelines. New pipelines are constantly being proposed (dark red) and constructed (orange).

The planned increase in fossil fuel extraction would expand the network of major oil and gas pipelines by at least 200,000 kilometers and create numerous additional oil and gas wells, roads, power plants, mines, oil and gas ports, refineries, Floating Production Storage and Offloading ships (FPSOs), Liquefied Natural Gas (LNG) Terminals, and much more. Figure 6 shows much of this infrastructure.

Previous research has shown that the social and environmental impacts of developing new oil and gas production frontiers has been, and could be, severe (Butt et al., 2013; Harfoot et al., 2018). Expanding fossil fuel production into areas with limited human interference would fuel the ongoing extinction crisis while simultaneously increasing carbon lock-in (L. Allen et al., 2011; Epstein et al., 2011; Hitaj et al., 2020). Using the systematized approach described above, it is possible to visually identify and describe the ecological and social threats and potential impacts of fossil fuel production projects (as described in Tables 1 and 2) in many ways. Figures 7, 8, and 9 show some global examples of the threats of fossil fuel production to biodiverse marine areas, the world's protected areas, and populations exposed to fossil fuel production infrastructure, respectively. While the mapping approach we have systematized is generally intended for use at the regional to local levels, these maps illustrate that this approach has utility at the global scale as well.

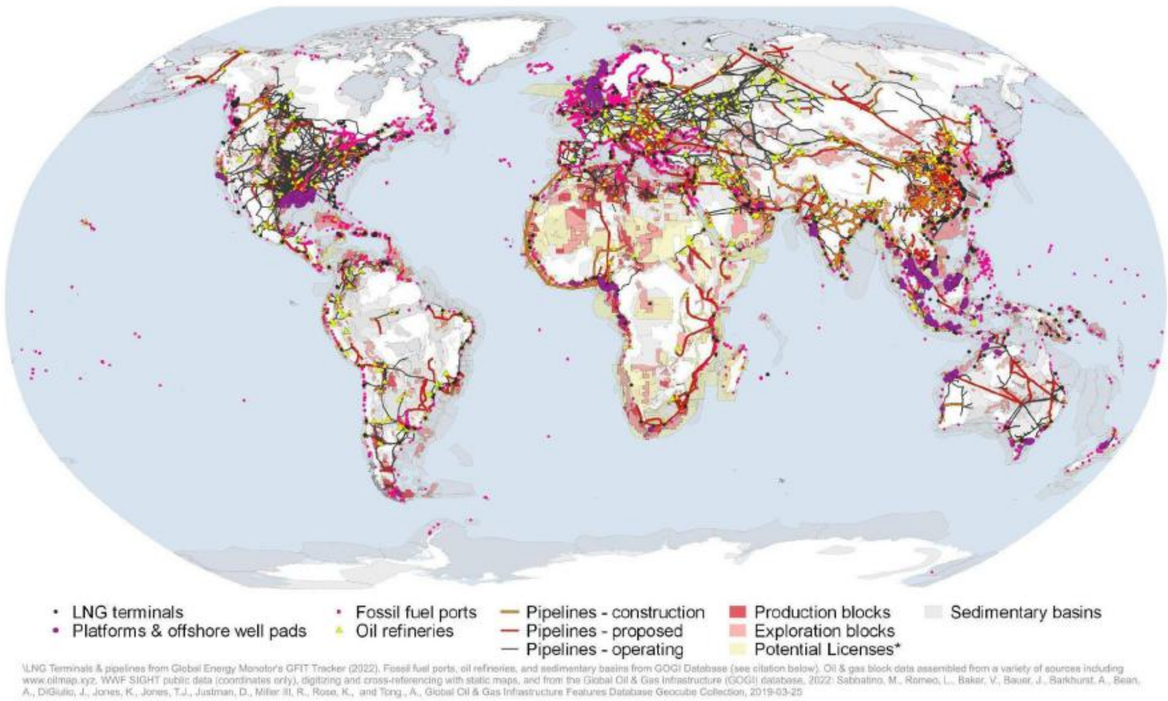


Figure 6. Major fossil fuel infrastructure of the world.

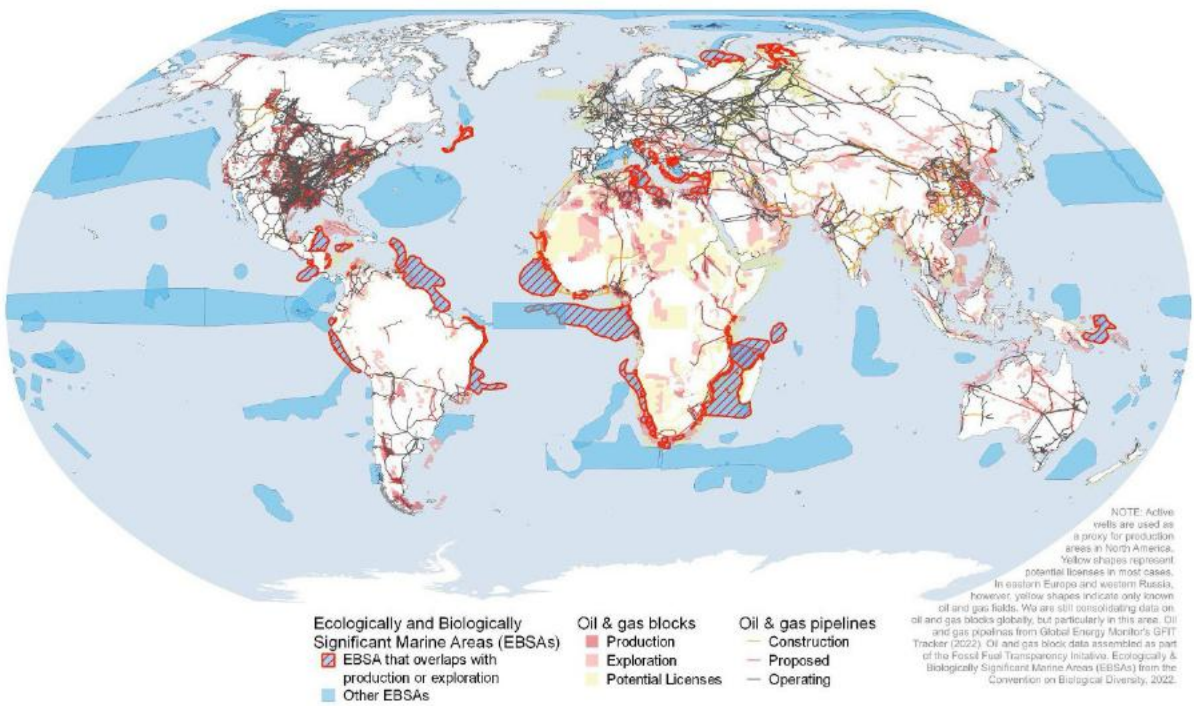


Figure 7. Overlaps between Ecologically and Biologically Significant Marine Areas (EBSAs) and oil and gas concessions.

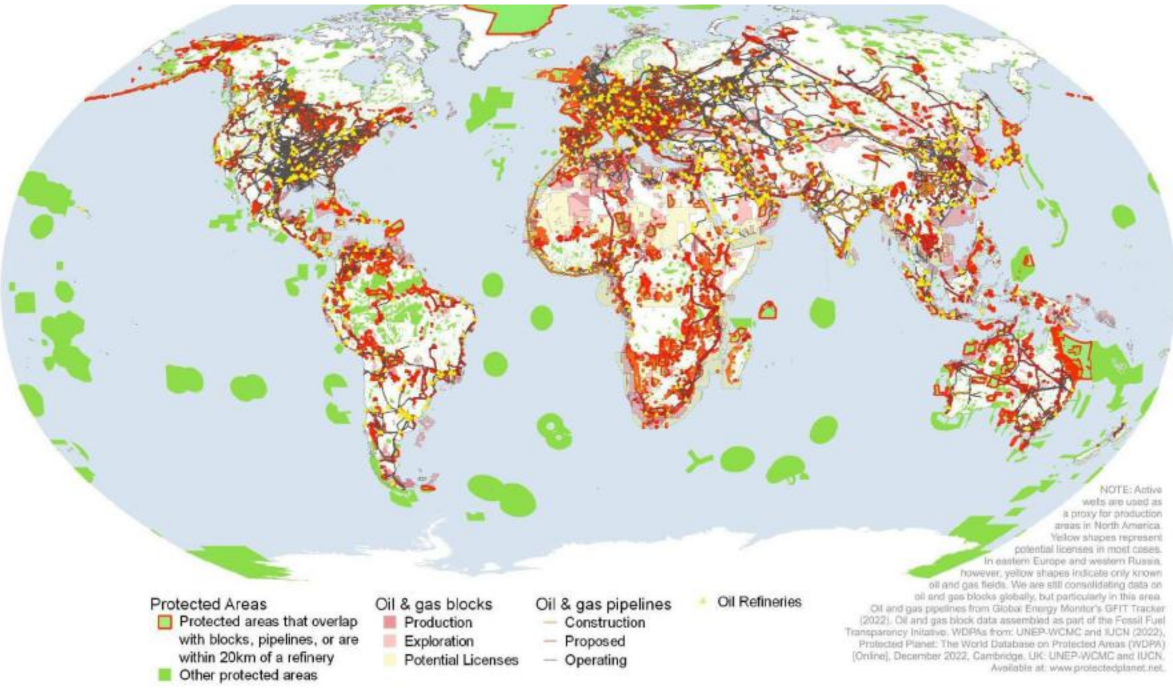
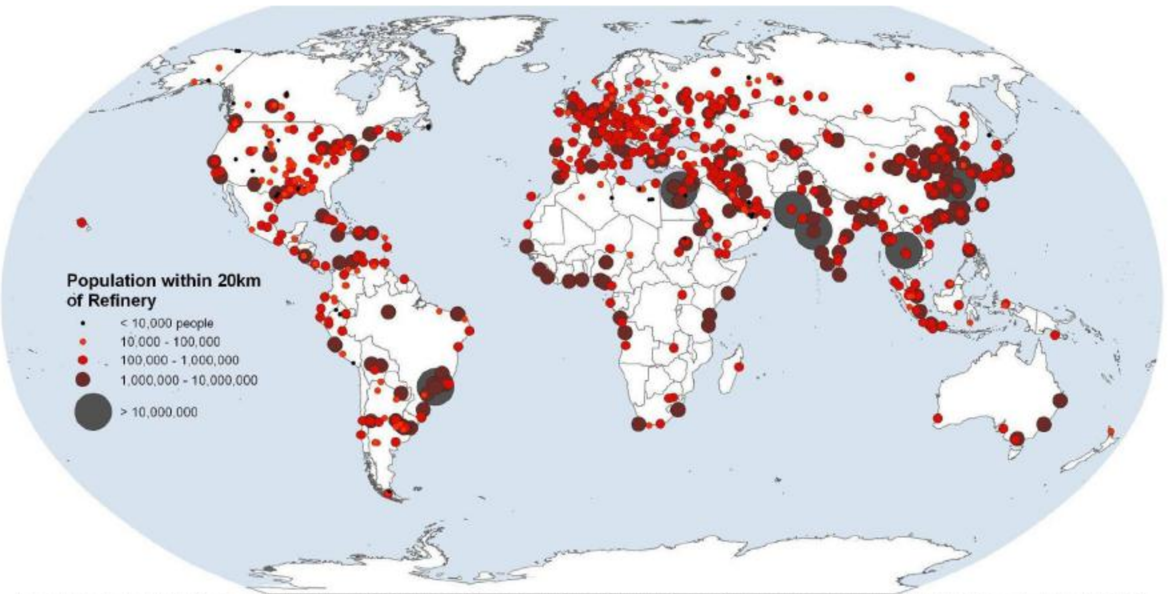


Figure 8. Overlaps between fossil fuel infrastructure (refineries, pipelines, lease blocks) and the world's protected areas. Of the 273,000 + protected areas in the World Database on Protected Areas shown here, over 43,000 of them (15.7%) overlap with current and planned fossil fuel production areas.



Refinery locations from the Global Oil & Gas Infrastructure (GOGI) database, 2022: Sabbatino, M., Romeo, L., Baker, V., Bauer, J., Barkhurst, A., Bean, A., DiGiulio, J., Jones, K., Jones, T.J., Justman, D., Miller III, R., Rose, K., and Tong., A., Global Oil & Gas Infrastructure Features Database Geocube Collection, 2019-03-25, https://edx.netl.doe.gov/dataset/global-oil-gas-infrastructure-features-database-geocube-collection, DOI: 10.18141/1502839
Exposed population derived from LandScan Global 2022, https://doi.org/10.48690/1527702

Figure 9. Population exposed to oil refineries. Over 700,000,000 people live within 20km of an oil refinery, putting almost 10% of the world's population at an increased risk of cancer from the fossil fuel industry (Williams et al., 2020). Population counts derived from LandScan Global (2022)

3. A mapping approach and online platform for identifying and visualizing the threats of fossil fuel production

Conventional risk assessment methodologies and analysis techniques aim to produce detailed quantitative estimates of the environmental risks and vulnerability associated with human activities such as fossil fuel development (Aps et al., 2009; Dinerstein et al., 2020; García-Ramos, 2004; Hightower et al., 2004; Kammoun et al., 2020; Nelson & Grubesic, 2018; Pierre et al., 2020; Udoh & Ekanem, 2011; Welsby et al., 2021). They are demanding in terms of data collection, expertise, and time, requiring intensive analysis and subsequent write-up. For example, data collection for the Department of Energy's Oil Spill Risk Analysis Model cost millions of dollars (Price et al., 2003). These quantitative risk assessment methodologies are used often in environmental impact assessment (EIA) processes, which are intended to support decision-making and stakeholder engagement. However, the legitimacy of public participation in these processes have been critiqued on many grounds (Bawole, 2013; Campero et al., 2021; Chi et al., 2014; Nadeem & Fischer, 2011).

Fossil fuel risk assessments are usually presented in an environmental impact assessment (EIA) in the leadup to the project approval decision, well after a project gains momentum with investors and governments. This effectively limits public participation in fossil fuel impact analysis to reviewing and critiquing highly technical EIAs, which are typically prepared by – or in close collaboration with – the project proponents. This arguably diverts attention from the question of public approval to the question of whether the EIA accurately captures the project's risks and potential impacts (e.g. Bawole, 2013). Clearly there is a need for an additional methodology of assessing the threats presented by fossil fuel production that provides widely/freely/publicly accessible/available and easily interpretable information well before a fossil fuel project is under way.

As a complement to standard quantitative risk assessment approaches, we have formalized a widely deployable, easily usable GIS-based approach for rapid spatial threat identification and visualization at sites of prospective fossil fuel prodn (Table 3). The approach described here is not meant to replace conventional quantitative risk assessment approaches, but rather to provide stakeholders with an early glimpse at the range of threats posed by a given fossil fuel project. This approach has been in use in disparate scientific research and efforts in civil society for many years (e.g. Finer et al., 2008). By formalizing this approach, consolidating large volumes of freely available spatial data (see appendix for examples), and integrating into the approach collaboration with groups to co-create content accordant with their needs, capacity, and ability to implement this approach on their own given the right tools, we hope to make this a widely available, free and intuitive way to show how planned fossil fuel projects threaten ecosystems, biodiversity, and local communities (as outlined in Tables 1 and 2).

Importantly, the approach we illustrate below provides an opportunity for stakeholders to raise credible concerns before a fossil fuel project acquires funding and gains traction with government, corporate and other non-state actors. This provides actors who would not or cannot engage in formal risk assessment or project approval processes the opportunity to express their voice, with reliable scientific data to back it up.

In collaboration, Stockholm Environment Institute, the Institute for Governance and Sustainable Development and the Global Energy Monitor are developing the Fossil Fuel Atlas to make this mapping approach available at scale. The Fossil Fuel Atlas (currently in alpha at www.fossilfuelatlas.net) is an open-access, free web mapping portal. The portal grants civil society users open access to our large curated database, as well as several engaging mapping tools for creating several types of content: interactive maps, map stories (which let you add text, images, etc. to compliment your map in an article-style format), and data dashboards capable of basic on-the-fly analysis (e.g. dynamic charts, tables and graphs that respond to how you move around their corresponding map).

The generalized form of the approach, as well as how the Fossil Fuel Atlas mapping portal makes this approach easily accessible at scale, is illustrated in the table below:

Methodological approach	How the Fossil Fuel Atlas makes it possible
Step 1: Identify threats of concern in collaboration with stakeholders.	To aid in this process, we have collected & analyzed a variety of peer-reviewed articles on the threats and impacts of fossil fuels production of various types, which are summarized in Table 1 and Table 2. This information will be made easily accessible on a fuel-by-fuel basis upon the launch of the web platform. We have found that stakeholders often already have threats in mind that they would like to illustrate. The literature we have consolidated helps serve as a scientific backstop to support stakeholders' needs.
Step 2: Select appropriate spatial datasets for the assessment, enriching data as necessary	See the Appendix for a list of the core databases we draw from (please contact us for the list of databases we use and/or our Web Map Services database). We have curated a one-stop database of fossil fuel data, social data, and environmental data in the Fossil Fuel Atlas mapping portal for use by stakeholders. Upon the portal's release, all datasets will be categorically sortable as well as findable by searching dataset titles and abstracts for keywords. These datasets usually need no additional cleaning, as they are either quite well assembled already or we have already made efforts to clean them. Most of them come from peer-reviewed literature, and the rest come from widely recognized data sources. All datasets include metadata and/or direct links to the original datasets. Users with previous GIS experience will find it easy to upload their own datasets and even create new spatial datasets directly within the Fossil Fuel Atlas mapping portal. The Fossil Fuel Atlas can also connect directly with QGIS, a popular open-source spatial analysis and visualization software, so users will be able to run geoprocessing on all datasets hosted within the Fossil Fuel Atlas' server. The Fossil Fuel Atlas already includes basic analytical capabilities via the Dashboard tool, but we will be adding more advanced capabilities in future iterations.
Step 3: Overlay fossil fuel data with environmental & social data to identify threats	After the appropriate datasets have been selected in the previous step, the Fossil Fuel Atlas makes it incredibly easy to overlay the appropriate datasets via the interactive map building tool.

Methodological approach	How the Fossil Fuel Atlas makes it possible
Step 4: Make the threats & potental impacts visually explicit	The Fossil Fuel Atlas includes advanced features for adjusting the symbology of layers (i.e. how the layers are visualized). Users can change practically anything about the way the data is visualized that could be done in typical desktop GIS software like QGIS.
Step 5: Assemble a final product based on intended use	The Fossil Fuel Atlas currently hosts three main tools for creating shareable content: interactive maps, map stories, and dashboards. All three types of content can be co-created by multiple users, embedded in other websites, and otherwise customized in accordance with users' needs. Additional mapping tools for the portal will be developed, based on feedback from partners.

Table 3: Step-wise methodological approach to the mapping

The mapping approach is expanded upon below:

1. Identify threats of concern with stakeholders

Below are some examples of the types of threats this methodology can help identify. This methodology is particularly useful, not only for synergistically identifying legal, environmental, and social threats, but also for identifying the cumulative threat that fossil fuel projects pose from a combination of several risks.

Legal Conflicts

» Internationally recognized protected areas (e.g. Ramsar sites)
» National and subnational protected areas
» International commitments (e.g. UNFCCC-NDCs, CBD—Aichi Targets)

Environmental Threats

» Endangered species
» Biodiverse areas, areas of high ecological integrity
» Already-degraded areas and areas close to tipping points

Social threats

» Freshwater resources
» Proximal communities
» Ecosystem-reliant livelihoods

Contributions to global threats

» Biodiversity loss
» Climate change
» GHG emissions from biomass loss
» GHG emissions from fossil fuel combustion

Risk multipliers

» Seismic activity
» Secondary impacts (logging, poaching, agricultural expansion, etc.)

2. Select the appropriate, publicly available spatial datasets for the assessment, cleaning or enriching them as necessary

Civil society groups will have full access to the entire data catalog, which will be easily searchable by keyword, category, data type, and more. The portal currently hosts approximately 100 datasets, with more being added all the time. Most of these datasets are the direct result of peer-reviewed research, and all the rest are from reputable organizations with expertise in the dataset's focus (e.g. endangered species distributions from RED List). Dataset enrichment could take many forms; for example, one could use zonal statistics to calculate the total population within a certain radius of a refinery, or run an intersect to identify major rivers that a known pipeline route crosses. We will be making spatial analysis tools available as much as possible via web portal user interface, but the portal also integrates directly with QGIS which hosts a vast array of geospatial tools.

3. Overlay spatial fossil fuel data with environmental and human data to identify threats and potential impacts

This will be a simple, intuitive task that can be carried out using the web portal. After the appropriate datasets are identified from the catalog, overlaying them is a simple task of using the interactive map making tool. Datasets can be re-arranged, the symbology changed, and the data filtered to show only specific subsets of the data by attribute or by geographic location.

4. Make the threats and potential impacts visually explicit

This step essentially involves changing the symbology of the areas of interest (changing colors, outlines, indicating affected areas with circles and other symbols, etc.). To ensure that threat/potential impact claims are based in fact, this technique must draw from the information on the threats of this specific fuel type and project as described in Step 1, as well as the contextual information from datasets selected in Step 2.

5. Assemble a final product based on intended use

The result of the analysis can be assembled in a variety of formal and informal ways based on the needs of the user(s). Modes of presentation are not mutually exclusive: SEI and IGSD issued the EACOP brief in a variety of forms to great effect. The mapping portal allows for the creation and sharing of interactive maps, map stories, dashboards, and also provides the ability to export maps as static images for use in reports or other materials.

4. Case-level uses of the approach

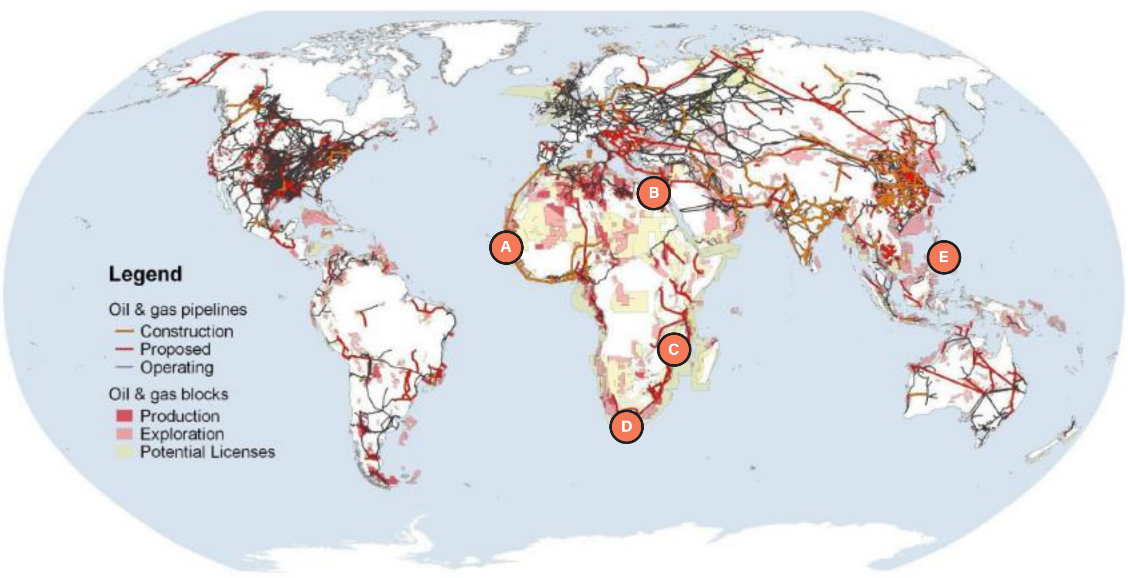
To pilot and test the value of such a rapid threat assessment approach at the project level, this section walks through several use cases of the approach. We are working with several partners in Africa—from Senegal, South Africa, Mozambique, and Egypt—and another in the Philippines to illustrate the specific threats they wanted to showcase.

» The first example illustrates threats to fisheries posed by fossil fuel production in the region of western Africa in general and Senegal specifically.

» The second illustrates the overlap between production areas in the Gulf of Suez, near the location of COP 27, and coral reefs that support biodiverse ecosystems and local economies.

» The third set of maps focuses on the threats of planned gas pipelines to water resources, carbon biomass, and protected areas in Mozambique.

» The final two sets focus on threats of fossil fuel production to biodiverse marine ecosystems.



NOTE: Active wells are used as a proxy for production areas in North America. Yellow shapes represent potential licenses in most cases. In eastern Europe and western Russia, however, yellow shapes indicate only known oil and gas fields. We are still consolidating data on oil and gas blocks globally, but particularly in this area. Oil and gas pipelines from Global Energy Monitor's GFIT Tracker (2022). Oil and gas block data assembled as part of the Fossil Fuel Transparency Initiative.

Figure 10. Case study areas

A. *Threats to fisheries and threatened species in Western Africa and Senegal*

A variety of upstream oil and gas projects have been proposed in Western Africa, including among others the Nigeria-Morocco Gas Pipeline (NMGP), the Greater Tortue gas extraction project, the Deepwater Tano Three Points project, and the Train 7 LNG Terminal expansion project (Figure 11 below).

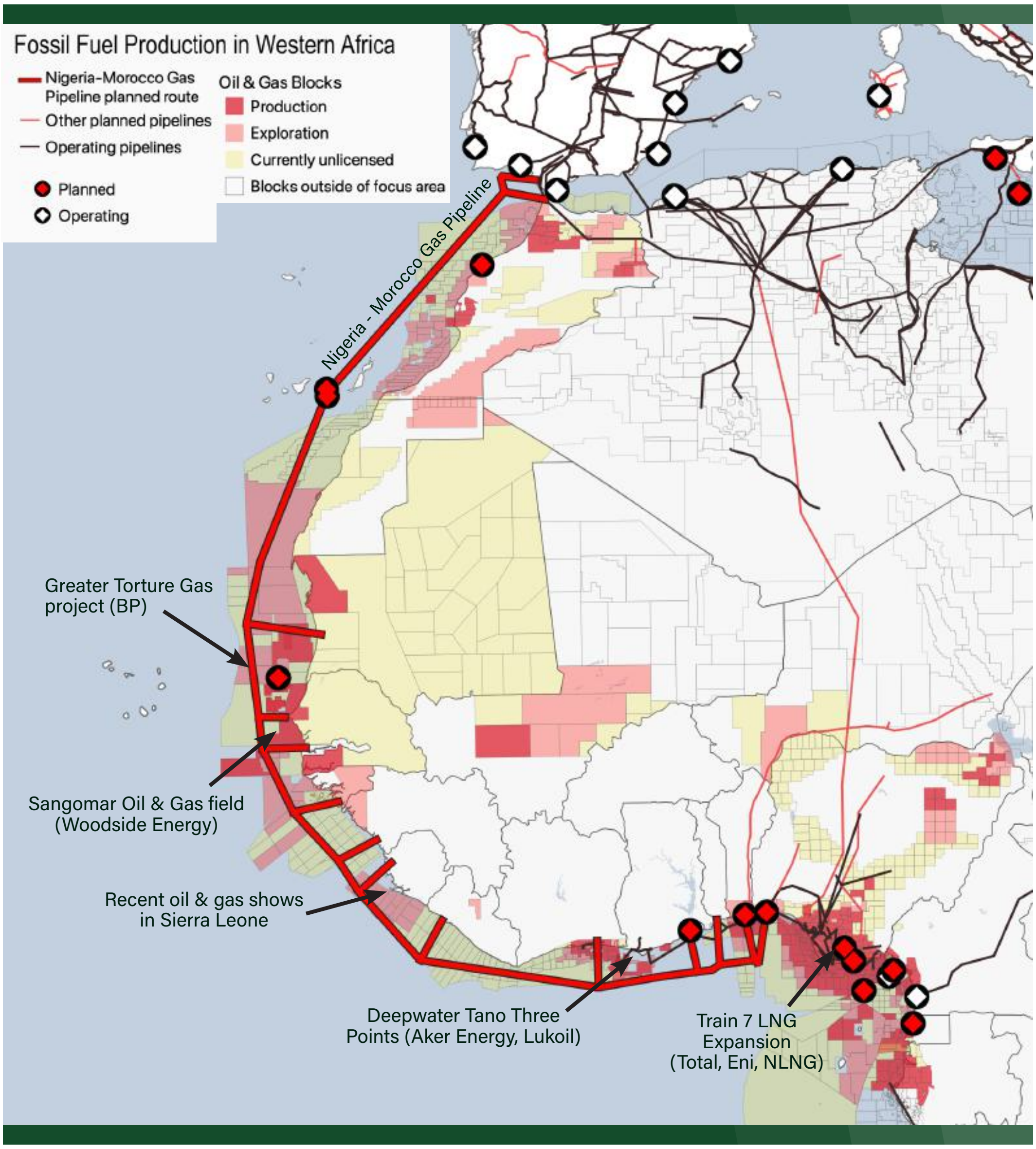


Figure 11. Overview of major fossil fuel production projects along the African continent's Western coast. As history shows, upstream oil and gas projects often produce a range of adverse social and environmental impacts (Tables 1 and 2; see also Butt et al., 2013; Ejiba et al., 2016; Kadafa, 2012; Karl, 2007). Owing perhaps to widespread exclusion from the 'participatory processes' of planned fossil fuel projects, such as the Offshore Cape Three Points and Greater Tortue Projects (OCI, 2021), many planned fossil fuel projects overlap with local fisheries and economically important coastal ecosystems.

Figures 12A - 12D below illustrate the extensive range overlap between currently licensed production and exploration areas, which can have some of the most severe impacts on marine species. Zoning restrictions around the pipeline and oil and gas fields could limit local access to these ecosystems already under threat.

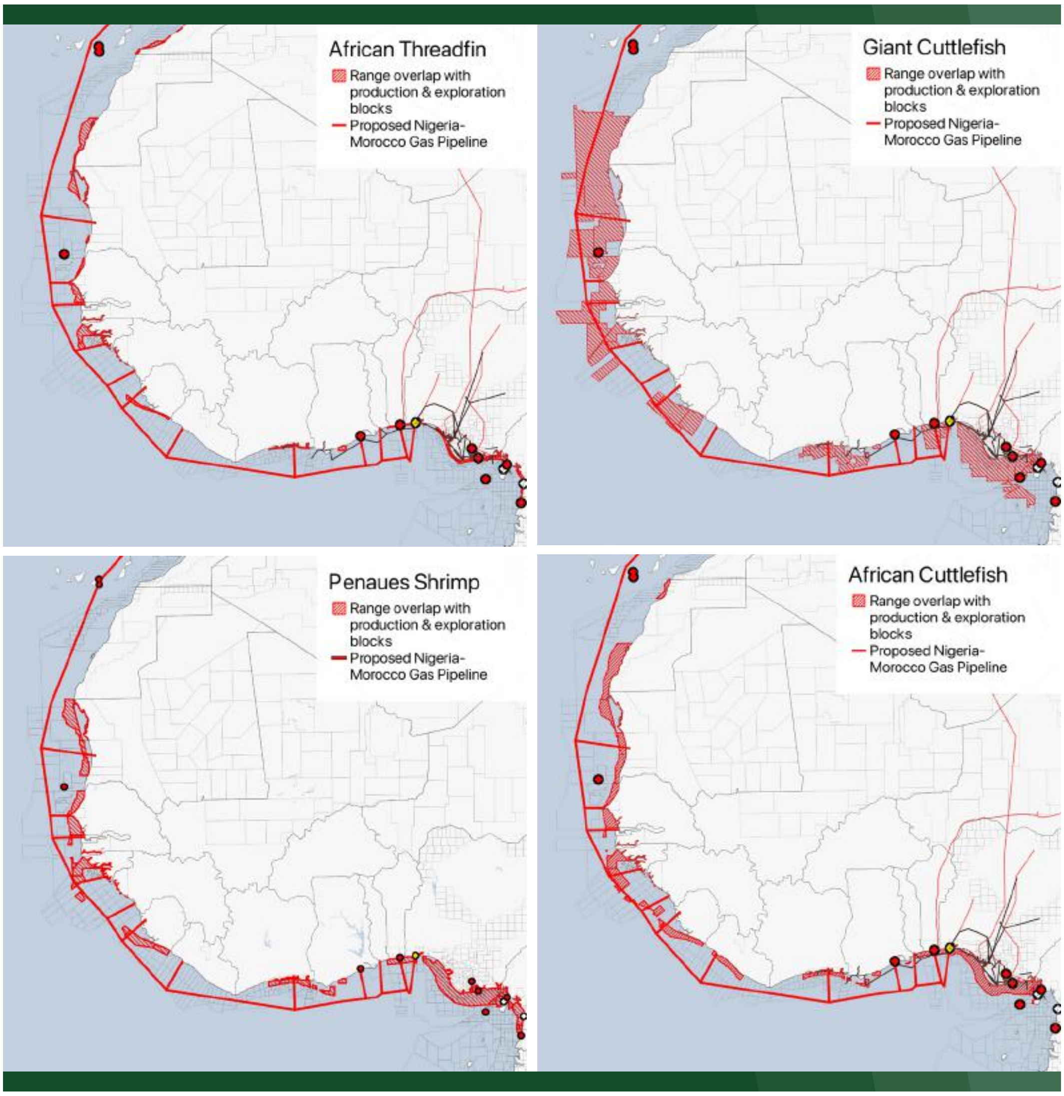


Figure 12A - 12D. Fish species overlaps with fossil fuel production and exploration areas off Africa's coast. Each of these species is commonly caught in artisanal or commercial fishing practices.

Previous research has already identified many biodiversity hotspots along Africa's coast as being threatened by oil and gas development (Harfoot et al., 2018), and this threat is growing with the burgeoning of new projects all along the coast. Western Africa is home to over thirteen percent of the world's mangrove forests, a type of coastal wetland ecosystem that provides numerous benefits to local communities in western Africa (see Fiture 13). Mangroves provide breeding grounds for oysters and shrimp, often harvested by local communities in artisanal fishing practices. Mangrove forests also provide protection against storms and prevent erosion, maintaining a fruitful environment for these local fisheries.

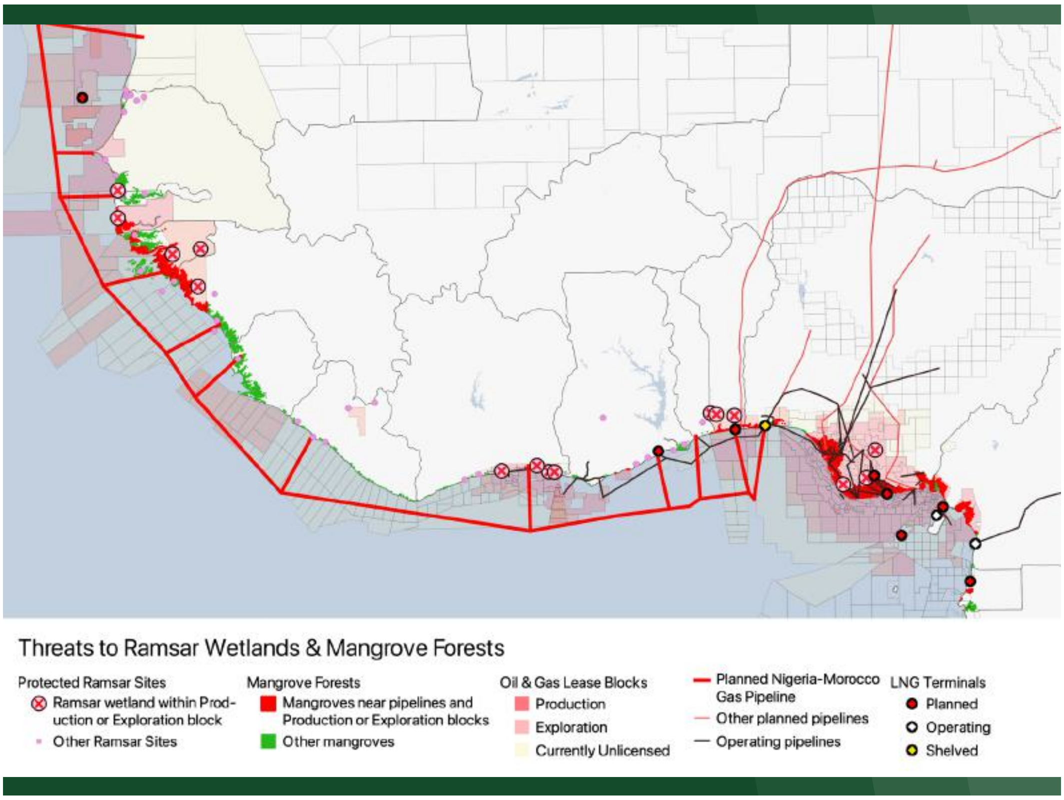


Figure 13. Threats to mangrove forests and protected wetlands from fossil fuel production in western-central Africa. Local communities often rely on mangrove ecosystems for subsistence, tourism and protection from flooding and other extreme weather events. Oil spills have been known to wreak havoc in mangrove ecosystems in western Africa (Pegg & Zabbey, 2013).

The Sangomar Oil and Gas Fields, located off the coast of Senegal, are operating less than 75 km from the highly biodiverse and locally important Sine-Saloum Delta wetland ecosystem and UNESCO World Heritage Site (Figure 14 below). A blowout, tanker spill, or even the cumulative effects of routine operations pose countless ecological and social threats to this area.

Photo: Sine-Saloum Delta wetland ecosystem with mangrove forests, Senegal. Credit: Claudiovidri

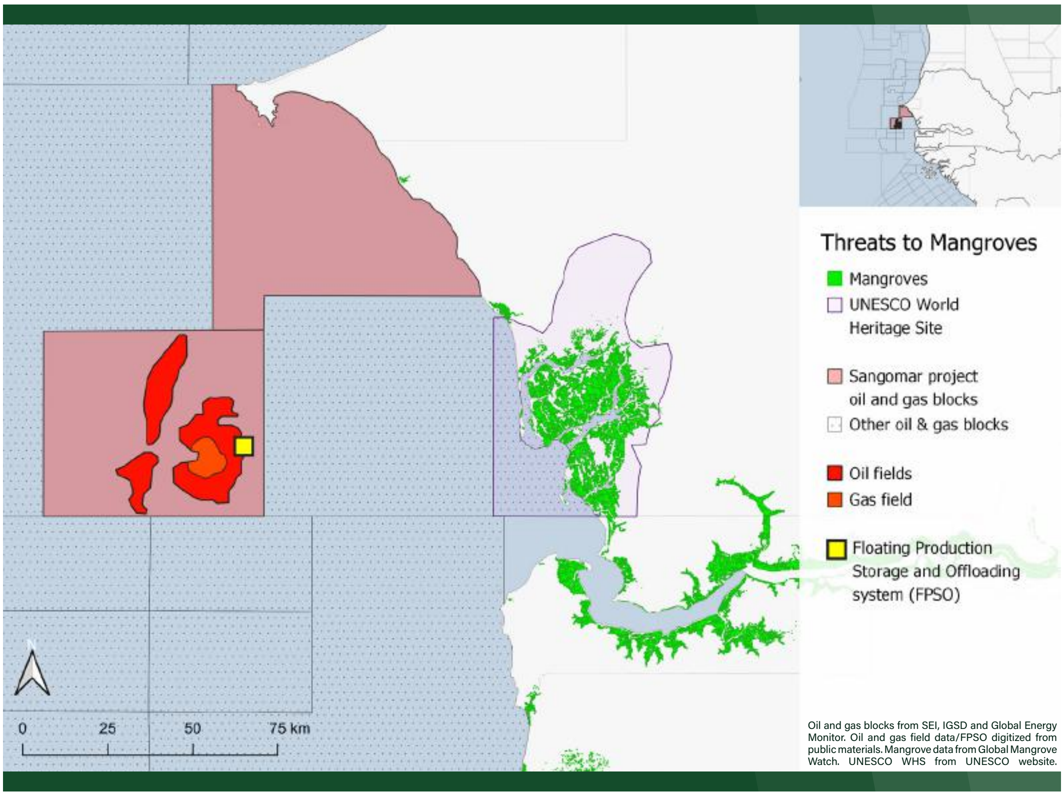


Figure 14. Our discussions with groups representing communities in the Sine-Saloum Delta wetland ecosystem (also a UNESCO World Heritage Site) indicated extreme levels of concern over the Sangomar Oil and Gas project, which could devastate local ecosystems and undermine local livelihoods.

Photo: Oil spills threaten vulnerable coastal ecosystems. Photo credits: Suphanat Khumsap

B. *Threats to biodiverse ecosystems and local economies in Egypt*

As shown in the map below, Egypt is a hotbed of fossil fuel production, and expansion is continuing (e.g. the new Zohr gas field off the northern coast).

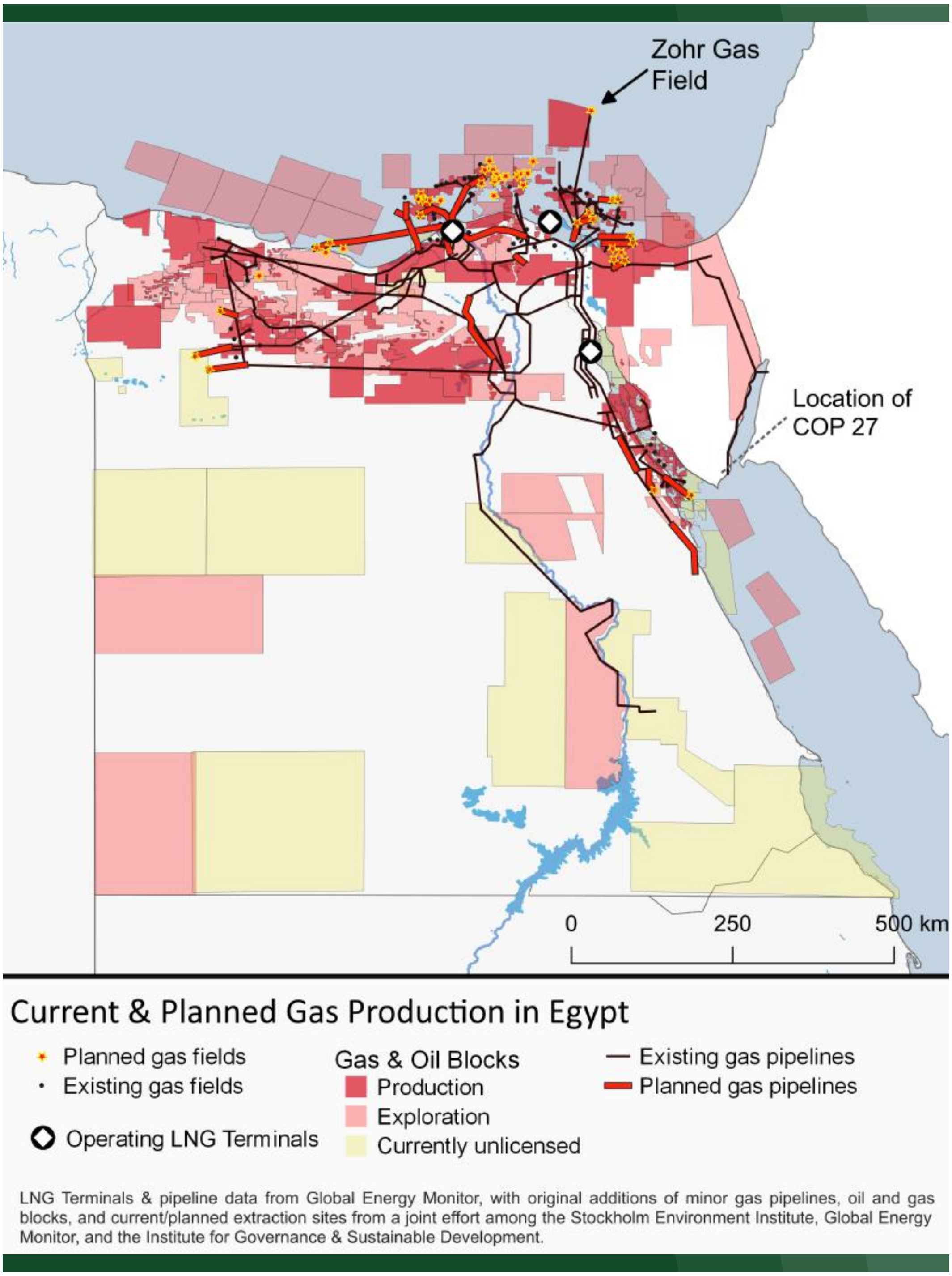


Figure 15. Overview of fossil fuel production in Egypt.

Much of the Gulf of Suez is licensed for fossil fuel production and exploration. Not only do many local communities in these areas rely on uncontaminated fisheries for subsistence, but for many the coral reefs that form the bedrock of these ecosystems are also a major tourist attraction and source of income. The dredging, toxic substance releases, zoning bans, and much more that accompanies offshore oil and gas production poses a threat to these ecosystems and the communities that rely on them. The map below illustrates this threat by overlaying the fossil fuel production data we explored in the previous subsection with a coral reefs dataset from UNEP.

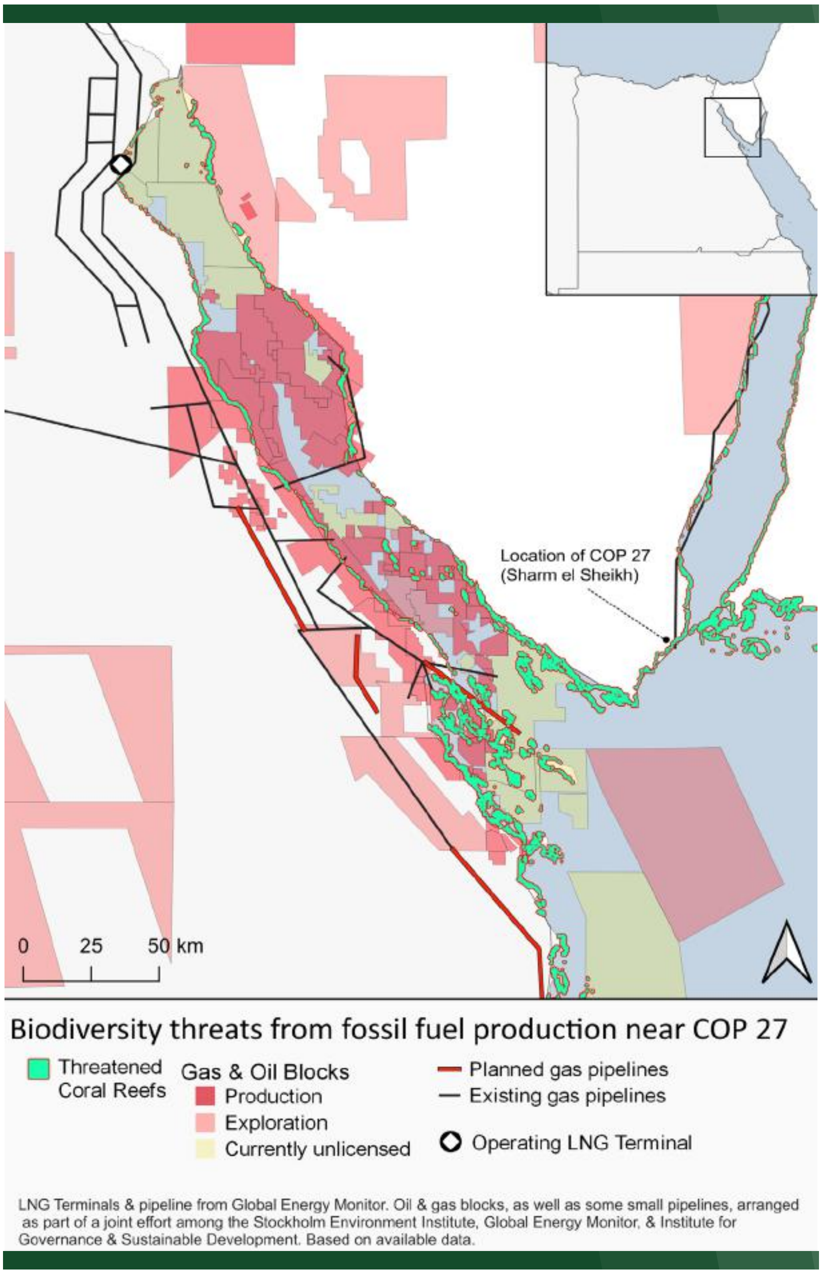


Figure 16. Overlap between coral reef and fossil fuel extraction areas in the Gulf of Suez.

C. *Threats to water resources, stored biomass and protected areas in Mozambique*

As is the case in Egypt, Mozambique has a long history of fossil fuel production. Recent discoveries in the offshore northern area have spurred renewed interest in pipelines that would export the bulk of these reserves to South Africa. Projects in the southern region of the country have been critiqued in the past for human rights abuses, environmental degradation, and entrenching local poverty (Gqada, 2013). The map below draws attention to the largest rivers in Mozambique which the proposed pipelines would cross.

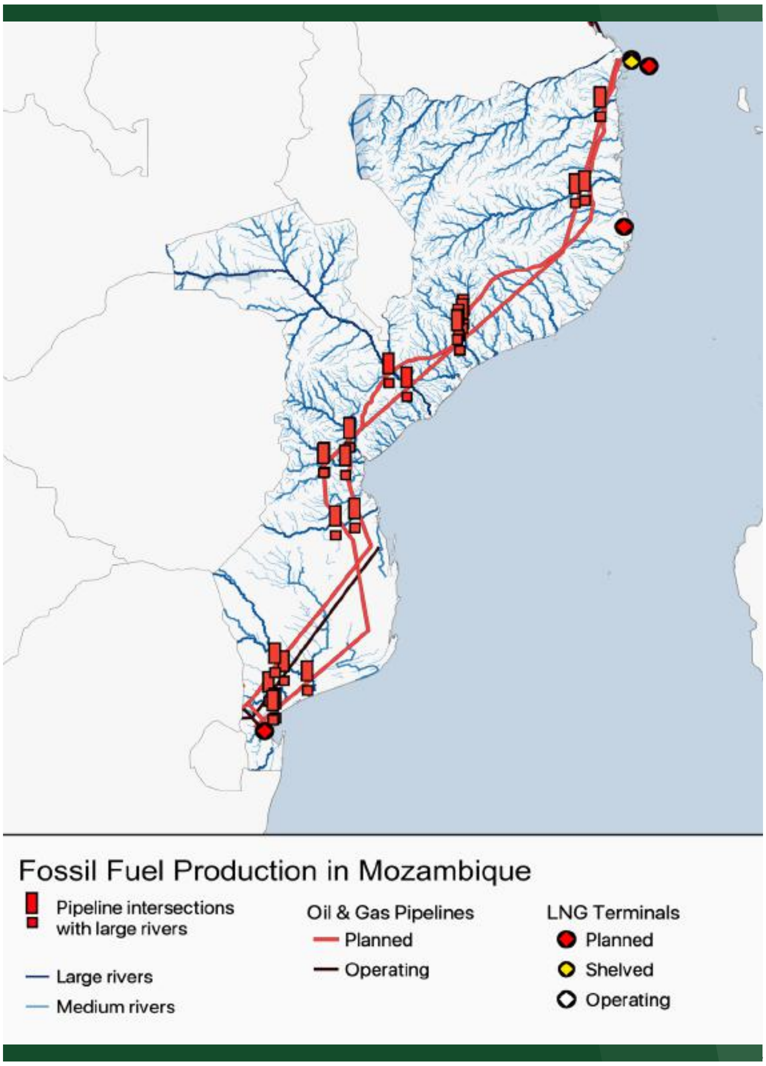


Figure 17. Threats to Mozambique's water resources from planned gas pipelines. Although gas pipelines don't carry the risk of spilling oil in these rivers, their construction still limits local access to fisheries, causes erosion and soil compaction, and brings numerous pollutants into river ecosystems from pipeline construction which can have impacts far downstream.

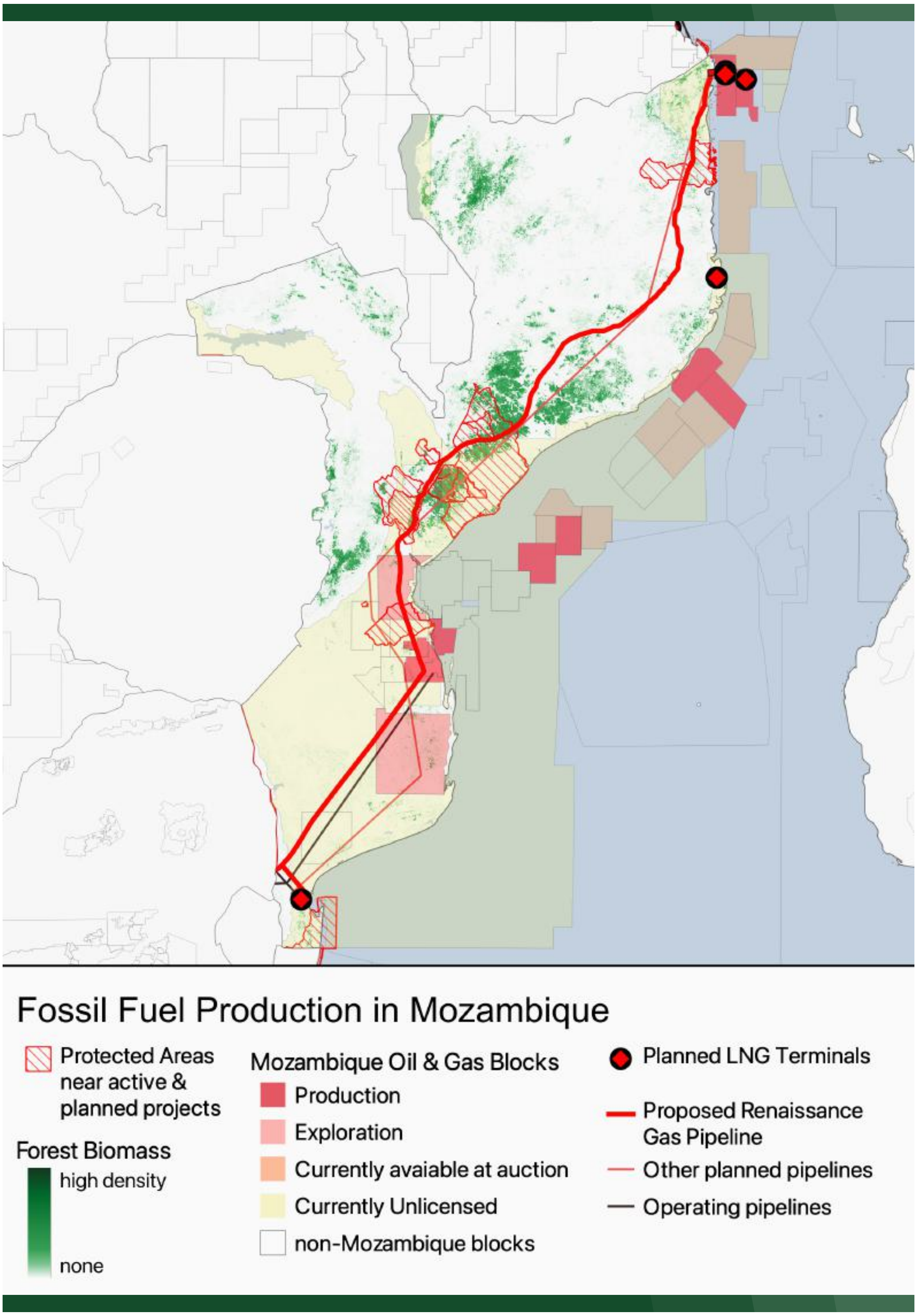


Figure 18. The proposed Renaissance Gas Pipeline could result in various environmental impacts, disturbing biodiverse and locally important such as the Zambezi Delta (a Ramsar site — largest protected area in map below) and causing significant biomass loss as wide swaths of trees are cut down along its planned route.

D. Threats to fisheries, marine biodiversity, and protected areas in South Africa

Many communities and groups in South Africa are concerned about the burgeoning of fossil fuel exploration and production off the country's coastlines. Working closely with partners in the area, we co-created maps to illustrate the marine threats of these projects to fish spawning grounds, whale and shark migration corridors, sea turtle populations, and marine protected areas. Maps focusing on two recently auctioned blocks are shown below in Figures 19 and 20.

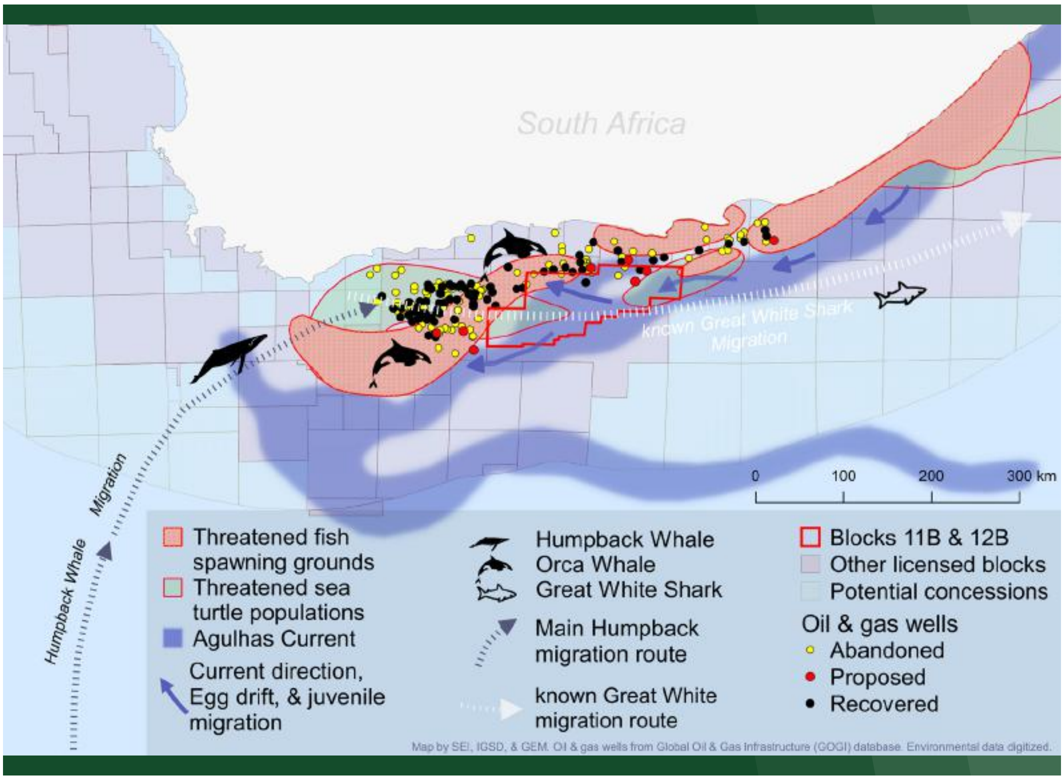


Figure 19. Threats to fish spawning grounds, sea turtle populations, and large migratory species from fossil fuel production off the coast of South Africa (Humpback whale off the southwest coast, killer whales off the southern coast, and great white shark migration in the south and southeast). Notice how the Agulhas current carries fish eggs from spawning grounds directly into the recently auctioned concessions.

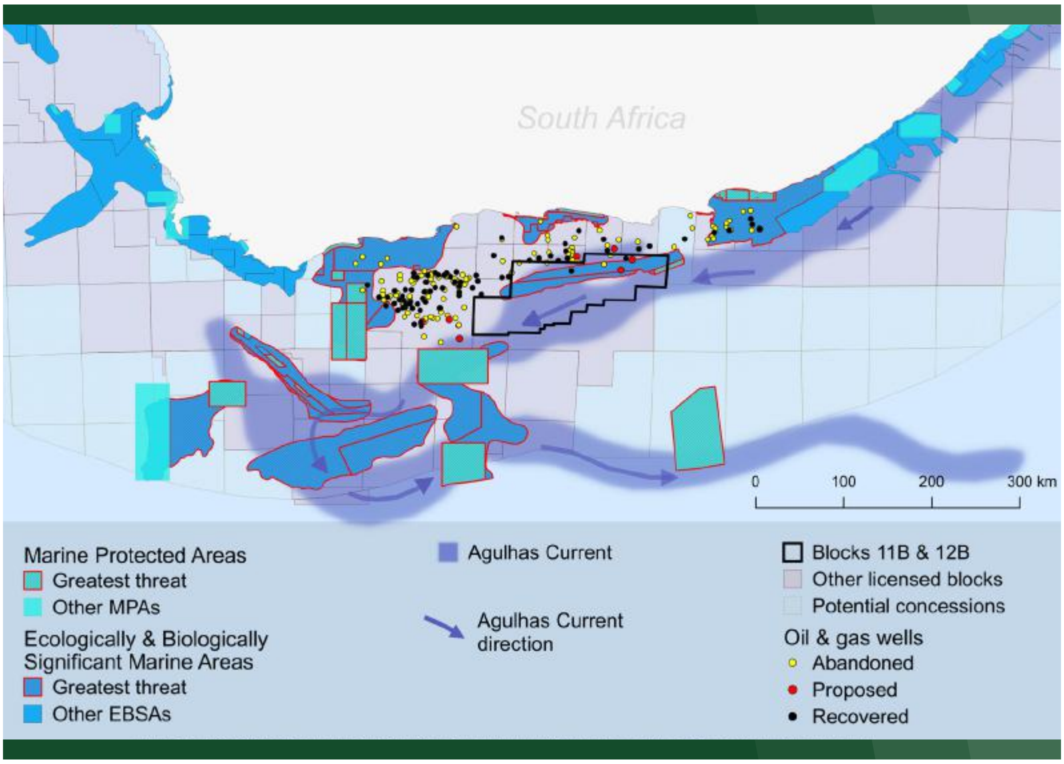


Figure 20. Threats to marine protected areas and designated Ecologically and Biologically Significant Marine Areas (EBSAs) from fossil fuel production off the coast of South Africa. Notice how the Agulhas current would carry pollution from extraction activities downstream into many additional marine protected areas and EBSAs.

E. Threats to biodiverse marine ecosystems in The Philippines

A final example is in The Philippines, where fossil fuel production projects overlap significantly with various coral reefs and biodiverse marine areas, many of which have been designated as Ecologically and Biologically Significant Marine Areas (EBSAs). Litigators were interested in illustrating the threatened EBSAs in addition to the coral reef ecosystems to support their arguments against expanding fossil fuel production in the country. EBSAs are an important category of protected areas as they are legally established under the Convention on Biological Diversity.

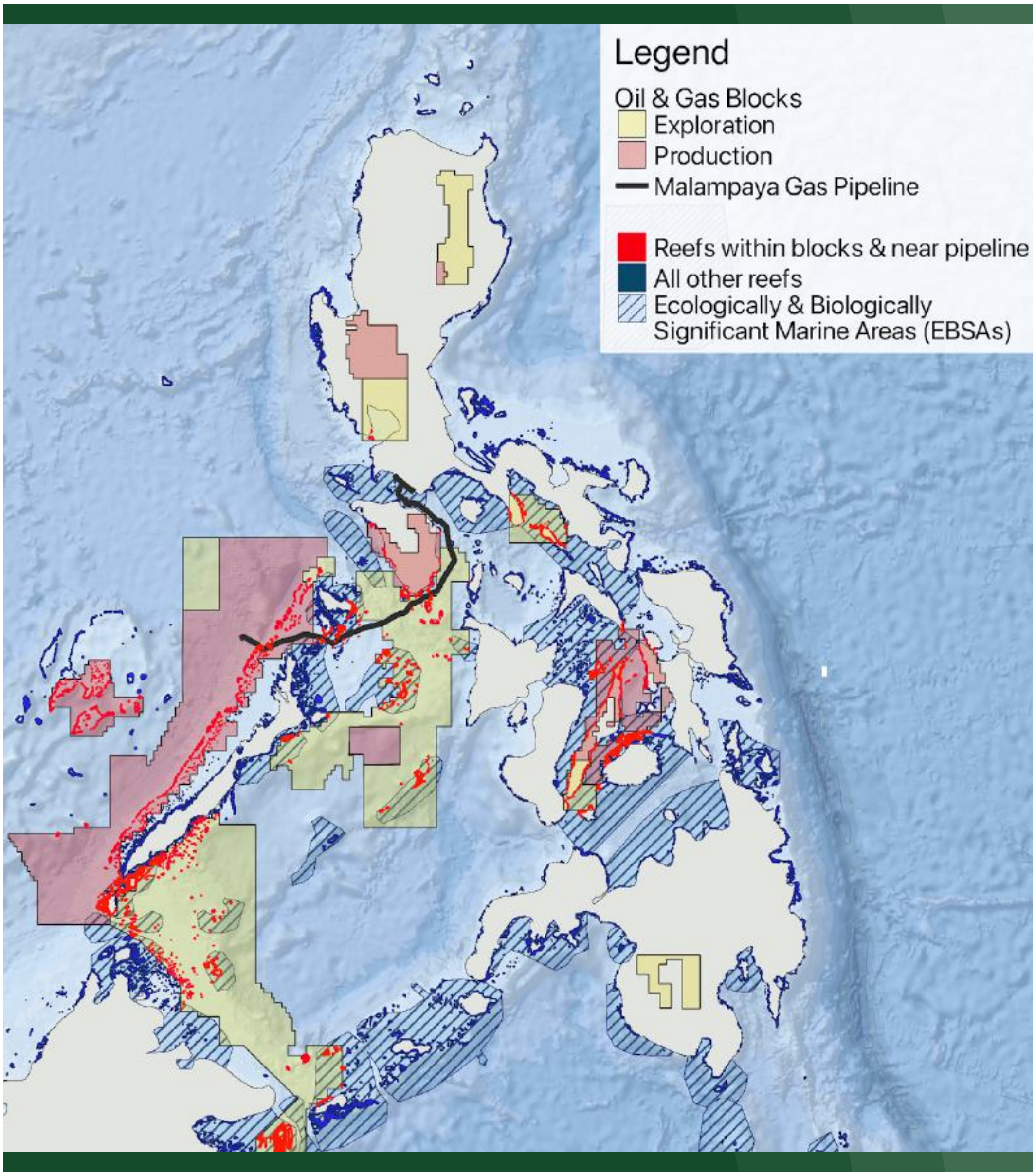


Figure 21. Coral reefs and EBSAs overlapping with fossil fuel production areas in The Philippines.

5. Conclusions

Humanity's continued reliance on the fossil fuel system threatens to open a pandora's box of runaway ecological deterioration, with irreversible and dire consequences for our species and the biosphere at large (Dinerstein et al., 2020; Lenton et al., 2019; Rinawati et al., 2013). Primarily driven by fossil fuel induced climate change (Urban, 2015), the unfolding extinction crisis is worsened by the various adverse ecological impacts of fossil fuel production (Table 1), as well as many other activities not discussed here. The transparency tool we are developing is an urgent step towards creating more transparency into the detrimental operations of the fossil fuel production supply chain, and the fossil fuel system as a whole. We hope this report makes clear the urgent need to make the threats of proposed fossil fuel production transparent and readily accessible.

The communities and groups that are affected by fossil fuel production often find themselves playing a constant game of catch-up, struggling to have their voices heard in environmental impact assessment processes and other decision-making processes, while meanwhile numerous other projects move forward with capital backing and support from decisionmakers. The forward-looking mapping approach and online platform we presented here is a flexible, light, and easily deployable mode of preemptively illustrating the various ecological, social, and climate threats of fossil fuel production. In addition to demonstrating the threats and impacts of individual fossil fuel production projects in a scientifically valid way, this methodology provides a means of visualizing and bringing attention to the issues associated with the global fossil fuel production network.

Issuing recommendations for creating a just, equitable clean energy transition is beyond the scope of this work. It has not escaped attention that fossil fuel production can have short-term economic benefits for certain parties despite many other economic, social, and ecological drawbacks. It is also recognized that many countries in the global north have been burning fossil fuels with impunity for over 200 years (such as the United States, which has the largest planned expansion of fossil fuel production of any country in the world). Creating fossil-free development trajectories while addressing the historical injustices in access to and exploitation of resources used for development will be essential as the world phases out the use of fossil fuels (Muttitt & Kartha, 2020). It is by no means an easy task, but it is imperative if we are to avoid catastrophic levels of climate change and ecological deterioration (Dinerstein et al., 2020; IEA, 2021). We hope that, in addition to making transparent the many ecological and social threats of fossil fuel production, the tools we are developing can support efforts to identify alternatives to fossil fueled development and help those alternatives be made a reality.

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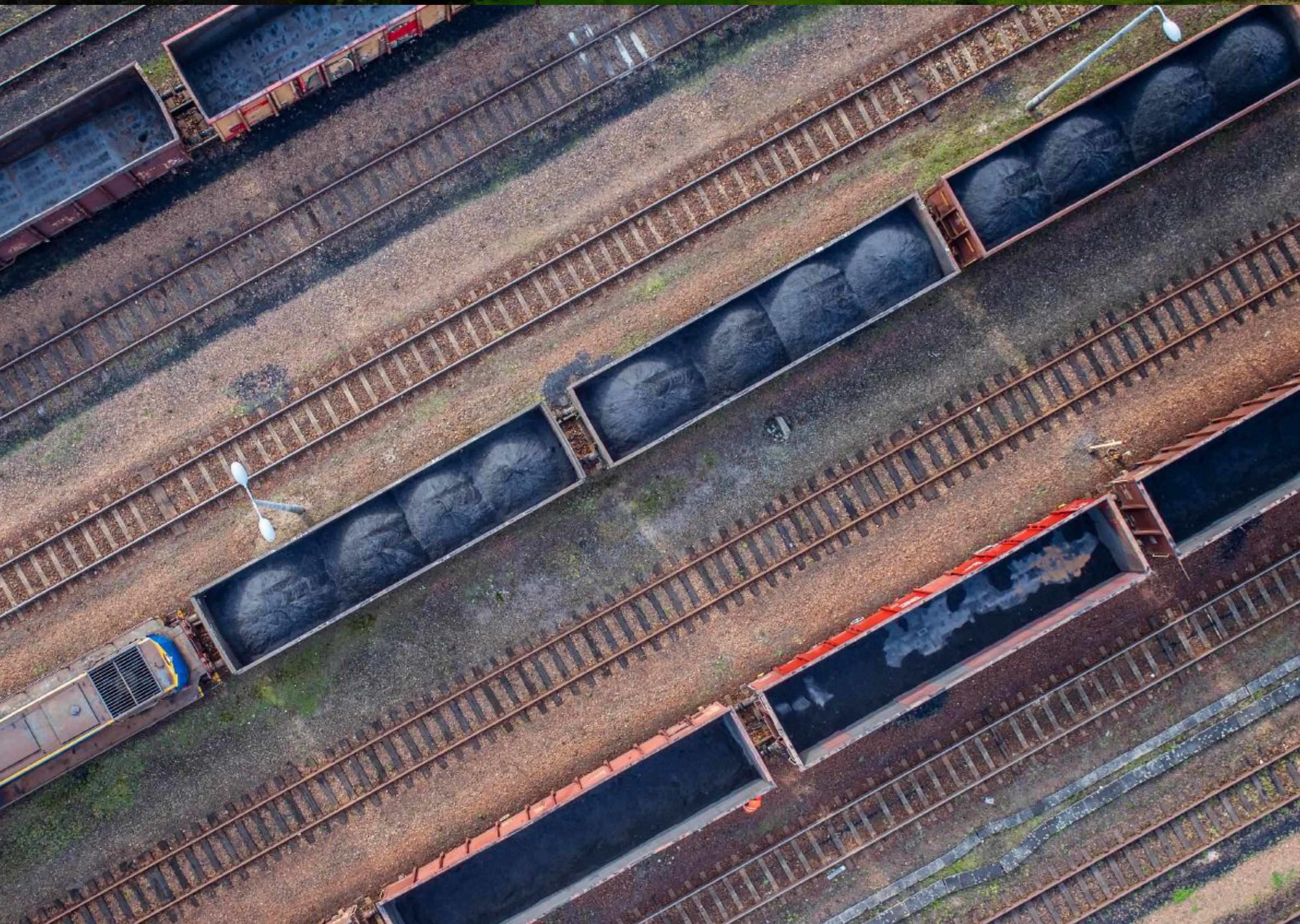
1.7

Appendix: Core spatial datasets

Dataset Name	Link
Global Distribution of Coral Reefs	https://data.unep-wcmc.org/datasets/1
GOIT (Global Oil Infrastructure Tracker)	https://globalenergymonitor.org/
GOGET (Global Oil & Gas Extraction Tracker)	https://globalenergymonitor.org/
Mangrove Habitat Extent	https://www.globalmangrovewatch.org/
LandScan Global	https://landscan.ornl.gov/
LandMark Global Platform of Indigenous and Community Lands	https://www.landmarkmap.org/
GGPT (Global Gas Plant Tracker)	https://globalenergymonitor.org/
Global Forest Height	https://glad.geog.umd.edu/dataset/gedi/
Ramsar Sites - Points	https://rsis.ramsar.org/
Ramsar Sites - Polygons	https://rsis.ramsar.org/
Global Forest Canopy Height, 2019	https://glad.geog.umd.edu/dataset
RiverATLAS	https://www.hydrosheds.org/products
BasinATLAS	https://www.hydrosheds.org/products
LakeATLAS	https://www.hydrosheds.org/hydroatlas
Africapolis	https://africapolis.org/en
EBSAs	https://www.cbd.int/ebsa/ebsas
Croplands	https://www.nature.com/articles/s43016-021-00429-z
Biomass (GEOCARBON)	https://datacore-gn.unepgrid.ch/geonetwork/srv/api/re-cords/5e695176-266d-4697-bc06-c2d9196845b4
Endangered Species	https://www.iucnredlist.org/
Species Richness	https://www.iucnredlist.org/resources/other-spatial-down-loads
Above-Ground Biomass	https://explorer.naturemap.earth/map
Areas of Global Significance for BIodiversity Conservation & Water Storage	https://explorer.naturemap.earth/map
Aquatic Fish Species Distributions	https://www.fao.org/fishery/en/knowledgebase/101
Seafloor Habitats & Seafloor Biodiversity	https://bluehabitats.org/
Global Coal Terminals Tracker	https://globalenergymonitor.org/
Global Coal Plant Tracker	https://globalenergymonitor.org/
Global Coal Mine Tracker	https://globalenergymonitor.org/
Field Data: Sea Turtle Nesting Sites & Sea Turtle Sightings	https://seamap.env.duke.edu/
Solar Potential	https://globalsolaratlas.info/map?c=11.609193,8.4375,3
Wind Potential	https://globalwindatlas.info/en
World Database on Protected Areas	https://www.protectedplanet.net/en/thematic-areas/wd-pa?tab=WDPA
Offshore Wind Technical Potential	https://energydata.info/dataset/offshore-wind-technical-po-tential
Exclusive Economic Zones (EEZs)	https://pacificdata.org/data/dataset/global-exclusive-econo-mic-zone-200-nautical-miles/resource/417d95b1-a25f-483c-a8cd-f8ba3301ccee



Fossil Fuel Atlas

Illustrating the threats of fossil fuel production —
A rapid threat identification methodology and platform

SEI Stockholm Environment Institute
Global Energy Monitor
IGSD Institute for Governance & Sustainable Development