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Energy Transition and Economic Sustainability

Energy has always been the cornerstone of economic growth. Through every stage of human civilizations, starting from the industrial revolution to the modern digital economy, fossil fuels have powered industrial production, transportation, and global trade (Bhattacharyya, 2011). The global economy remains heavily reliant on fossil fuels, despite progress in solar, wind, hydropower and nuclear energy. Because of the current economic structure is built around cheap and abundant oil, any major transition will require restructuring of industries, supply chains, and even urban infrastructures (Sager, 2015).

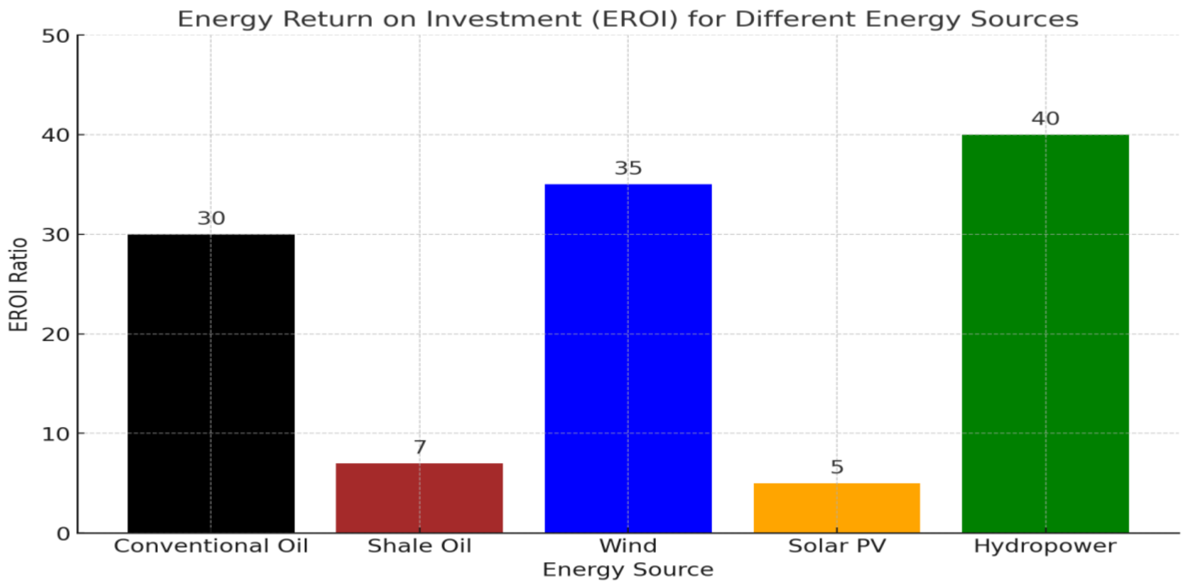
The nearing transition is predicted to have a substantial consequence on securing energy and economic stability. Often wondering if the renewable energy can sustain the ever-growing economy, or will the transition impact global market and political landscape?

With the limited natural resources at our disposal, we all knew a day will come where our basins dry up, causing increased exceeding extraction cost while shrinking revenues. As predicted, that energy tipping peak is estimated to be around 2025. Peak oil refers to the concept of reaching the maximum point of global crude oil production, after which supply enters irreversible decline. Despite being delayed in the past, we have finally arrived. Hence, the energy landscape is at a crossroads. Nations are facing the inevitable decline of conventional crude oil reserves, while mildly resisting transitions to continuous and sustainable alternative source of energy.

Energy politics poses a significant influence on the US economy. In the past, the United States was heavily dependent on foreign oil until the shale-oil came online. Then, the U.S. became the world's top oil producer (~13.5 M bpd) with shale-oil adding nearly 8.6 million barrels per day (bpd) (as of December 2024) for the past two decades (EIA, 2023). However, tight oil wells are facing rapid depletion rates with around 60 – 70% decline in less than three years and productivity falling off by 35% compared to 2023 levels (Goehring & Rozencwajg, 2024). Meanwhile, shale extraction sites are facing increased environmental concerns.

Energy Return on Investment (EROI) is an essential metric for evaluating the economic viability of different energy sources. The EROI values of conventional oil range 30-100:1, provided an abundant energy surplus that fueled industrial growth. As conventional reserves deplete, the world is increasingly relying on low-EROI energy sources like shale-oil (5-10:1) and solar PV (2.5-10:1) (Murphy & Hall, 2010).

Historical EROI values and biophysical economic frameworks can be used to analyze the challenges and opportunities presented by the shift from fossil fuels to renewables. In recent years the global energy trends indicate that remaining conventional reservoir will require more energy-intensive extraction methods with reduced gain. This is creating an instance to invest additional towards renewable, for the sake of the environment at least. Some of the initiatives include the European Green Deal which aims to make the EU climate-neutral by 2050 and the U.S. Inflation Reduction Act supports clean energy innovation (European Commission, 2023).



Renewable Energy Alternatives

Using the values of EROI values we can compare the energy alternatives and their potential to drive the economy. Energy analysts argue that while renewables like wind (18-50:1 EROI) and hydropower (30-50:1 EROI) are reaching competitive values, issues like intermittency, storage limitations, and infrastructure dependence on fossil fuels pose major challenges(International Energy Agency [IEA], 2023).

1. **Hydropower**

Hydropower boasts a high EROI (30-50), though its capacity to fully replace fossil fuels remains limited. This is because majority of the hydroelectric generating sites has been built already, leaving little room for expansion. To build a new dam faces high cost, long development time, geographic and geological constraint in addition to environmental concern. It can serve as a key component but has to be supplemented by other sources. New innovations like Pumped-storage hydro (PSH) and advanced energy storage solutions will be necessary to maximize hydropower's potential in a low-carbon future.

2. **Wind Power**

Wind power sources have strong EROI value and easy to install. It's deemed safe with minimal operation cost. But it's limited to the weather patterns and storage. Thus, not yet ready to drive it fully but can be added to the mix.

3. Nuclear Power Plant

Reactors with Uranium-238 as a fuel, generates a dense energy with a tiny pellet output equating 149 gallon of fuel. At ~90% capacity factor and zero CO_2 emission to coal's 40-50% and significant CO_2 emissions, without a doubt is the best option. Despite its efficiencies, in case of a mishap they are potentially deadly and hazardous. When dealing with Nuclear, safety and radioactive fissile waste management is the prevalent issue. In addition, site's starting, operational and maintenance cost is estimated in billions. Small modular reactors (SMRs) striding to provide safer and more efficient nuclear energy.

Whether it's due to geographic, weather, storage, and radioactivity problems we haven't found an affordable replacement with surplus as fossil fuel yet. By investing in advanced solid-state batteries, hydrogen fuel cell and smart grids, we are improving renewable energy reliability gradually. The major drawbacks here are these technologies are still developing, and large-scale deployment remains costly and logistically complex. Currently, AI-driven energy estimations are mitigating the challenges of renewable intermittency (IEA, 2023).

By leveraging the technological advancement, delaying the effects of oil-peak can be possible. It was done twice in the past (in 1970s and 2000s) through offshore drilling and shale revolution consecutively. Except expansion of a new offshore drilling is needed. With it comes an intertwined course of opportunity and possible geopolitical tension. The Arctic, for example holds substantial untapped oil reserves. However, disputes between Russia, the U.S., Canada, and Norway over these resources could lead to new geopolitical tensions (Delannoy et al., 2021).

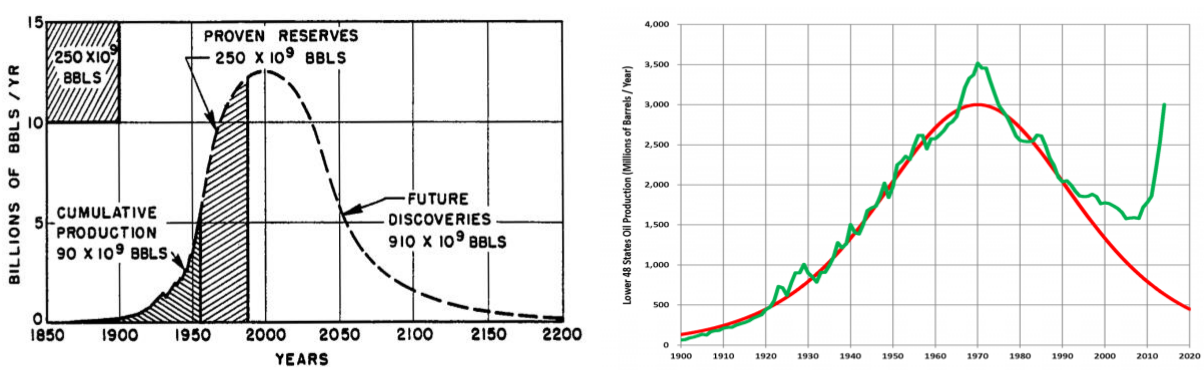


Fig: Hubbert Peak projections and delays (in 1970 & 2000s)

In the past, offshore drilling has caused Falklands War (1982) and disputes in the South China Sea (Smith, 2019). Avoiding these wars are crucial path forward for the world's stability and human safety. Alarming as that is, many of the heavy weights are armed with nuclear weapons with potential to wipe out civilizations and populations. With that said, you can't help but wonder, has the cozying of the US government towards the Russians, aim to normalize diplomacy and secure untethered access while avoiding major wars.

Despite the apparent urgency some experts argue that rushed energy transition could trigger economic stagnation or depression due to supply constraints and increasing energy costs, (Delannoy et al., 2021). For an effective transition strategy, they require either government policy intervention(e.g., carbon taxes, subsidies) or market-driven innovation. Nevertheless, markets tend to resist rapid change unless profitability aligns with policy goals. Oil companies continue investing in fossil fuels because demand remains strong, subsequently delaying the transition (Sager, 2015).

In recently conducted surveys, about 67% American public prefer alternative energy development over fossil fuels (Pew Research, 2023). Except for regions that depend on fossil fuel jobs. Understandably so, they are still resisting change. This creates an opportunity to address the issue at an everyday working American's level and work towards inclusive solution. Governments worldwide are investing increasingly in clean energy, with nearly $2 trillion in global funding since 2020 (IEA, 2023). The main task is ensuring an equitable transition that does not leave oil-dependent communities behind. These indicate a careful and sensible strategy should be employed in the sectors where first-hand shock will be experienced.

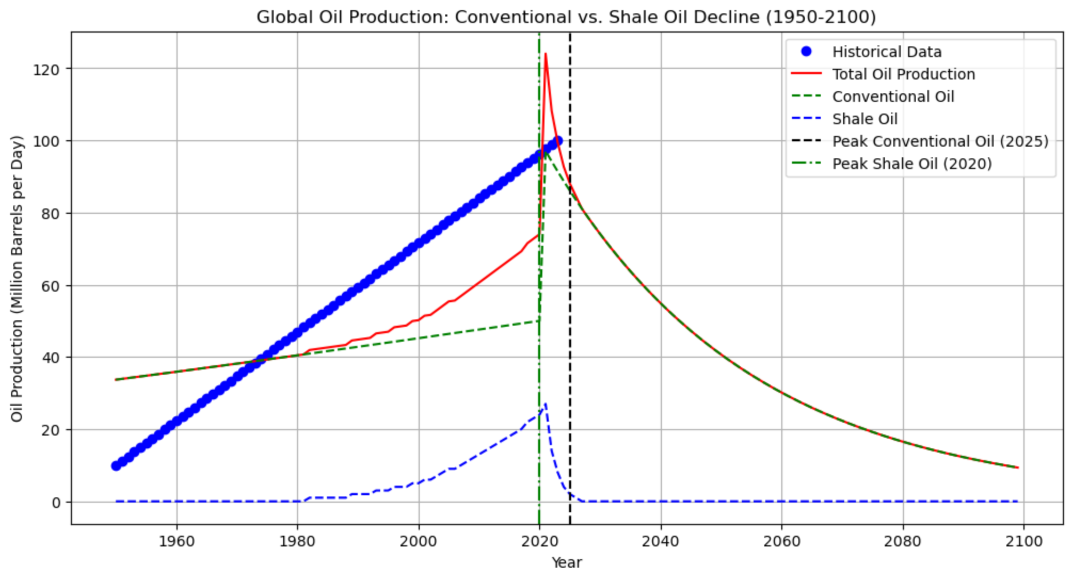
The 2025 oil peak is expected to redefine traditional global energy strategies. Although fossil fuels have previously driven industrial growth, declining EROI values dictate an urgent shift toward more sustainable alternatives. Shale, offshore drilling and technological improvements may sustain economic growth short-term. But in the long-term, due to excessive tight-oil depletion and economic instability, the government will need to immediately dedicate resources to build renewable energy infrastructure. The challenge lies in balancing energy security, economic resilience, and technological innovation without creating a massive tectonic shock.

At this juncture, choosing the right path might be crucial. Both delaying or adapting early will impact the future geopolitical influence and economic stability. As the rate the climate change effect is going, timing will be the single most decisive factor. Therefore, the success of efficient energy transition will directly depend on early investment of smart grids, storages and technological evolution to alleviate major disruption of the system while ensuring smooth transition. A mismanaged transition has a potential to impact global supply chains, employment and financial market. Now is the time to act.

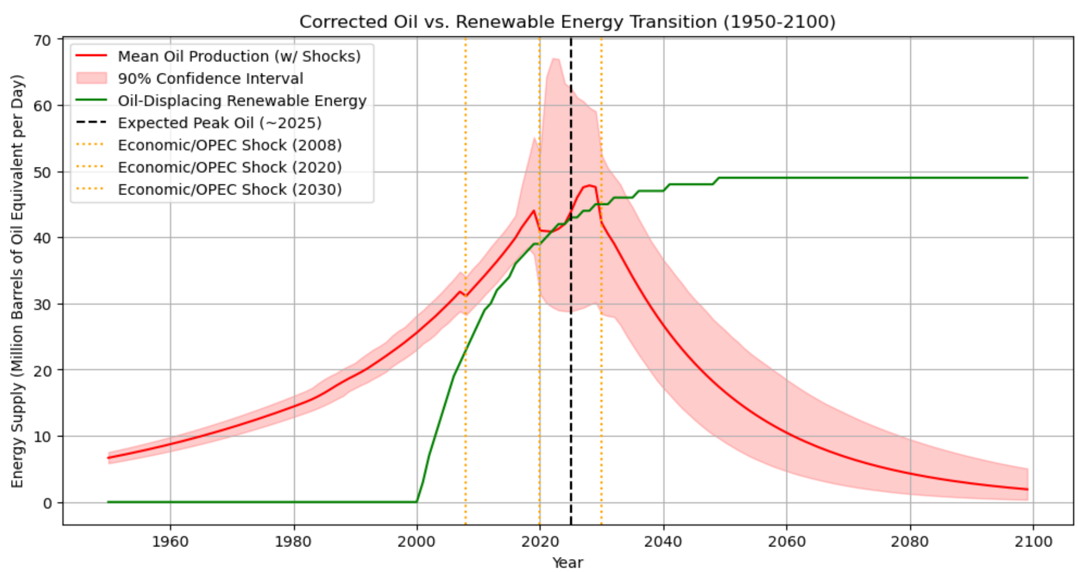
Additional Note

From the original Hubbert model, if we can predict the new peak and how it will project the future of fuel, how would it be?

This is developed through extrapolated data from the past fuel production and with a decline at the rate of -5% to -7% annually. With an expectation of short-term over production. It's just an estimate.



Montecarlo predictive model with added confidence level. Giving our past shocks and predictive expected energy shock due to overcompensation.



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