A peer reviewed version is published at: https://doi.org/10.1016/j.scitotenv.2016.01.127

Oil, Earth mass and gravitational force

Khaled Moustafa

Editor of the Arabic Science Archive (ArabiXiv)

E-mail: khaled.moustafa@arabixiv.org

Highlights

- Large amounts of fossil fuels are extracted annually worldwide.
- Would the extracted amounts represent any significant percentage of the Earth mass?
- What would be the consequence on Earth structure and its gravitational force?
- Modeling the potential loss of Earth mass might be required.
- Efforts for alternative renewable energy sources should be enhanced.

Abstract

Fossil fuels are intensively extracted from around the world faster than they are renewed. Regardless of direct and indirect effects of such extractions on climate change and biosphere, another issue relating to Earth's internal structure and Earth mass should receive at least some interest. According to the Energy Information Administration (EIA), about 34 billion barrels of oil (~4.7 billion metric tons) and 9 billion tons of coal have been extracted in 2014 worldwide. Converting the amounts of oil and coal extracted over the last 3 decades and their respective reserves, intended to be extracted in the future, into mass values suggests that about 355 billion tons, or ~ $5.86*10^{-9}$ (~ 0.0000000058) % of the Earth mass, would be 'lost'. Although this is a tiny percentage, modeling the potential loss of Earth mass may help figuring out a critical threshold of mass loss that should not be exceeded. Here, I briefly discuss whether such loss would have any potential consequences on the Earth's internal structure and on its gravitational force based on the Newton's law of gravitation that links the attraction force between planets to their respective masses and the distances that separate them.

Keywords: Earth mass; fossil fuels; oil depletion; gravitational force; consequence oil depletion; oil extraction; climate change;

Million years ago, dense populations of plants, animals and microorganisms have lived, perished and sedimented as organic matter. High temperatures and pressures 'cooked' the accumulating organic matter over a long time and produced fossil fuels in the form of coal, oil, and gases embodied in sedimentary rocks as integral parts of rock structures and Earth mass. The first commercial oil wells have been drilled in 1850s (Taverne, 2008). Since then, fossil fuels have been extensively extracted in tremendous amounts from around the world to fulfill the energy needs of the Industrial Revolution. According to the US Energy Information Administration (EIA) (http://www.eia.gov), the production of oil in 2014 was estimated at about ~ 93 million barrels per day (Table 1). Considering that one barrel of oil weighs about ~140 Kg in average (depending on oil grades and density), the weight of oil pumped out in 2014 would be: 93,000,000*140*365 = 4,752,300,000,000 Kg (~ 4.75 trillion tons). During the last 34 years (from 1980 to 2014), the total amount of oil produced worldwide is estimated at about ~ 132 trillion tons (Table 1).

The production of coal, for its part, has significantly increased from 1980 to 2012. In 1980, it was about 4 billion tons, and in 2012 it has almost doubled (~ 9 billion tons) (Table 2). The total production of coal during the last 32 years (1980 – 2012) is estimated at about ~186 billion (0.186 trillion) tons (Table 2).

The total mass of oil and coal extracted during the last 34 years (1980–2014) would thus be: 132 trillion ton oil + 0.186 trillion ton coal= 132.186 trillion tons (~132,186,000,000,000 Kg).

On the other hand, the reserve of oil is estimated at about 1,655,560,000,000 barrels[1] (~ 231,779,000,000,000 Kg) and the reserve of coal at about 979,791,000,000 Kg[2]. The total reserves of both oil and coal would thus be: 231,779,000,000,000 Kg Oil + 979,791,000,000 Kg Coal = 232,758,790,000,000 Kg (~ 233 trillion tons). Subsequently, the total sum of oil and coal extracted during the last 34 years and their respective reserves would be 132 +233 = 355 trillion tons (or 350,000,000,000,000 Kg) ($\sim 3.5*10^{14}$ Kg).

By reporting this value to the value of the Earth's mass estimated at about $5.97*10^{24}$ Kg[3] (5,972,190,000,000,000,000,000,000 Kg), which includes the mass of the atmosphere estimated at about 5.1480×10^{18} Kg (Trenberth and Smith, 2005), we find that the mass of the oil and coal already extracted during the last 34 years and their respective reserves, intended to be extracted in the future, would represent about $5.86*10^{-9}$ (~0.0000000058) % of the global Earth mass. In other words, about 0.0000000058 percent of the Earth mass would be 'lost' in the form of burned oil and coal. Although this percentage may appear tiny, a small percentage of a gigantic number such as the Earth's mass would represent an important overall value. Moreover, the real amounts of the extracted oil and coal should be greater than the estimated here, if we should take into account the amounts of oil and coal that have been extracted before 1980, for which no relevant statistics are available.

As such, the questions that could be raised here are: what would be the potential consequences of fossil fuel extraction and burning on Earth's mass at the long-term? What would be the effects on the Earth's internal structure and on its gravitational force in regard

[1] https://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=57&aid=6&cid=ww,&syid=2014&eyid=2015&unit=BB Accessed 20 January 2016

[2] https://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=1&pid=7&aid=6&cid=ww,&syid=2011&eyid=2011&unit=MST Accessed 20 January 2016
[3] http://solarsystem.nasa.gov/planets/earth/facts Accessed 20 January 2016

A peer reviewed version is published at: https://doi.org/10.1016/j.scitotenv.2016.01.127

with neighboring planets and stars based on Newton's universal law of gravitation that links the gravitational force proportionally to the mass? According to Newton's law, two planets in the universe attract each other with a gravitational force (F) that is proportional to their corresponding masses but inversely proportional to the square of the distance between them (Fig. 1). The force (F) can be calculated through the equation: $F=gm1*m2/r^2$, where '*F*' is the attraction force between two masses (*m1* and *m2*), '*g*' is a gravitational constant and '*r*' is the distance between the two planets or masses (from center-to-center). Subsequently, if the Earth loses some of its mass in the form of oil and coal burned overtime, the question is: would Earth gravitational force and its rotation be impacted in whatever way with respect to other planets or stars? If so, how, and to which extent such impacts could be avoided or reverberated on Earth?

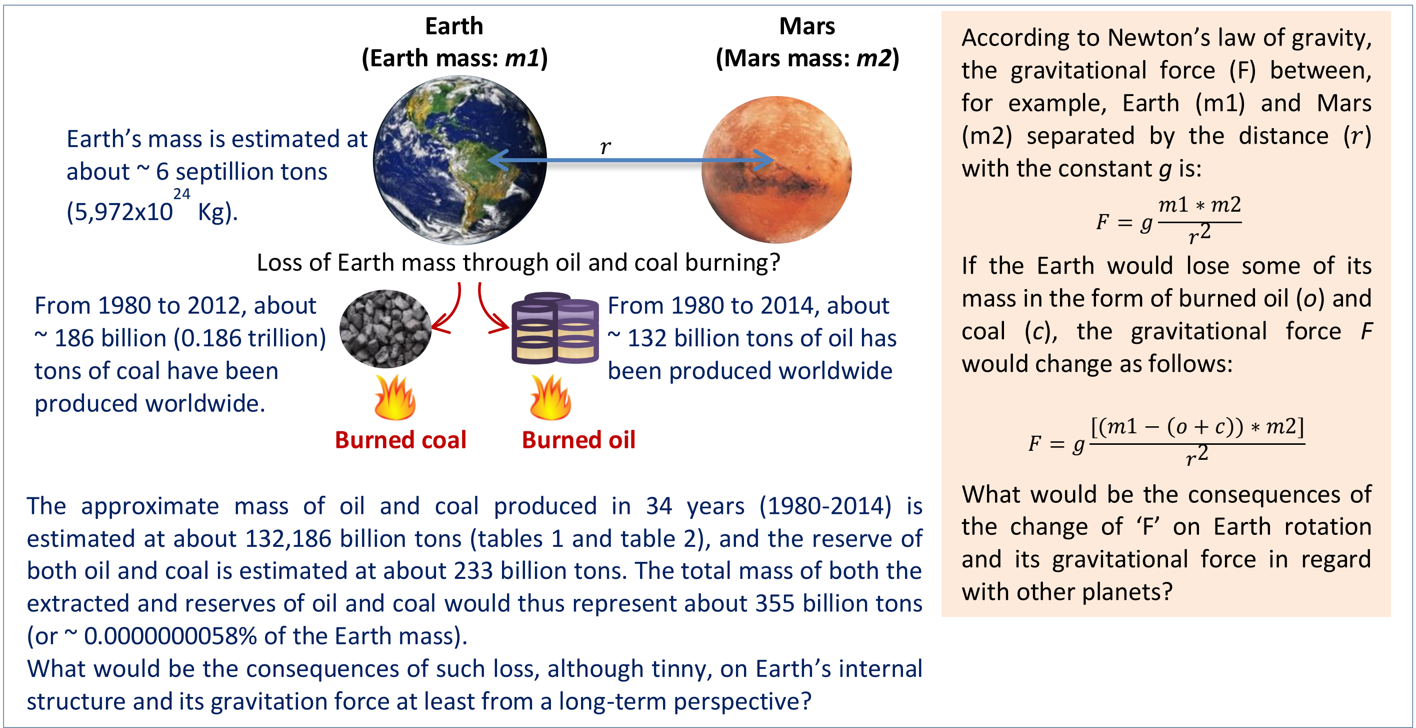

Figure 1. According to Newton's universal gravity law, planets attract each other through a force (F) that is proportional to their masses and inversely proportional to the distance between them (r).
By extracting and burning trillions tons of oil and coal during centuries, Earth would lose some percentage of its mass. What would be the consequence of such losses on Earth's gravitational force vis-à-vis other planets, particularly neighboring ones (i.e. Venus and Mars) or between Earth and moon or Sun?
If such a loss has any potential effects on the Earth gravitational force, then what would prevent neighboring planets from 'failing' on Earth, or inversely, if Earth is losing some of its mass progressively, where the mass is a determinant factor in maintaining gravitational relationship with other planets based on Newton's law of gravitation?

One, however, may argue that the potential loss of Earth mass in the form of burned fossil fuels would fit in Lavoisier's Law, "*Nothing is lost, ... everything is transformed*", but extracting enormous amounts of fossil fuels from Earth would move a large part of Earth mass from one part (Earth interior) to another (Earth surface and atmosphere in the form of gases; mainly CO_2), potentially resulting in the fragilization of the Earth's internal structure relative to its state upon formation about 4.5 billion years ago (Dalrymple, 2001). Additionally, the major part of the extracted fossil fuels is burned, and therefore, one metric ton of extracted fossil fuels will never produce one metric ton of counterpart products to eventually maintain comparable or proportional masses between the extracted and transformed fossil fuels. In other words, the loss of Earth's mass by burning oil and coal would not be compensated by new deposits of oil and coal as quickly as they are depleted nor by similar mass of transformed byproducts obtained by industrial operations to ultimately maintain the same global mass or the same terrestrial attraction force related to its final mass. Extensive extractions of oil and coal over large regions may also 'fragilize' their internal or underground structure and would increase the rate and intensity of Earthquakes as the huge rocky spaces filled by oil and coal are fully exhausted and remain either empty or filled with other liquids or water whose density is different from oil and coal, hence exerting different pore pressures that may affect the earthquake frequency and magnitude. Recent studies tend to support such claims particularly near the water-injected sites (Ellsworth, 2013; Frohlich, 2012; Keranen et al., 2013; Keranen et al., 2014; van der Elst et al., 2013). It was also reported that earthquakes could be induced either by fluid injection or by fluid extraction (Segall, 1992) (Nicholson and Wesson, 1992) (Yerkes and Castle, 1976). In fact, seismicity would be correlated in time and space with oil production from some oil and gas fields where pore pressures may decline substantially by several tens of megapascals (Segall, 1989) inducing seismic instabilities at both local and regional scales (Grasso, 1992). On the other hand, the interest in developing industry of unconventional natural gases such as the shale gas continues to grow with potential adverse impacts on the environment and public health (Hays et al., 2015) (Meng, 2015) (Prpich et al., 2015) although this is still debatable (Werner et al., 2015).

It took billions years to form energy fossils as integral parts of Earth's structure and consistency. However, as the internal activity of Earth evolves permanently (Davies, 1999) and as human activities significantly and rapidly modify the rate and timing of geomorphic processes (Goff et al., 2015), the chemical and geophysical changes caused by oil extraction and depletion may affect Earth dynamism and its subsequent evolvability. It is very likely that enough time has not been elapsed yet to perceive concrete consequences of the intensive depletion of organic fossils which, however, may trigger one day a series of accelerated and unstoppable geological events, particularly when vast regions are completely depleted. Toward reducing this from happening, other energy sources than fossil fuels may need to be developed urgently. If substantial efforts and research investments comparable to those spent on the development of infrastructure for fossil fuel energy would be devoted to the development of safer and sustainable alternative energy sources (for e.g. solar energy, artificial photosynthesis, etc.), the consequences of oil depletion on the global ecosystem could be delayed, should they cannot be completely avoided.

Although new knowledge for the management of the global ecosystem can be acquired from existing data without needs to new experiments or infrastructure (Specht et al., 2015), a modeling or a simulation of the loss of Earth mass in the form of burned oil and coal (Fig 2) might be required to assess the importance of the loss of terrestrial mass and to probe its potential effects on Earth structure and on its universal gravitational force in regard to other neighboring planets. Interdisciplinary research and collaborations, spanning geology, physics,

A peer reviewed version is published at: https://doi.org/10.1016/j.scitotenv.2016.01.127

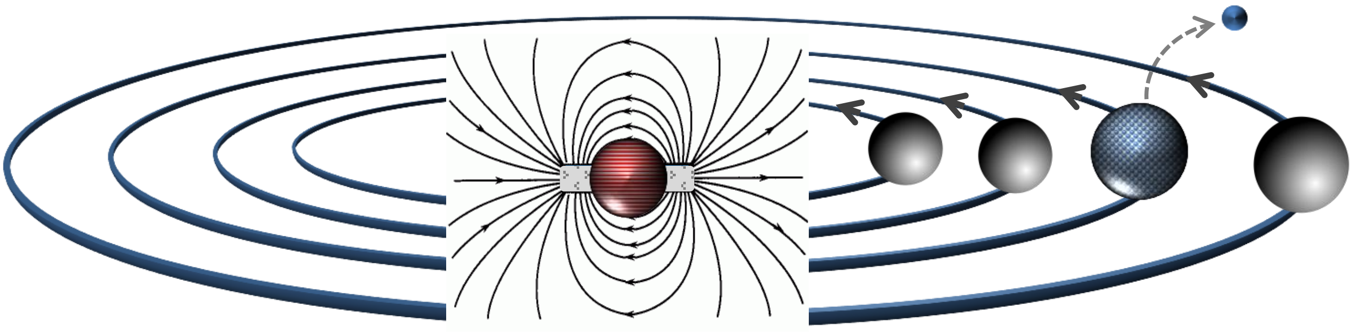

Figure 2. A streamlined modeling scheme for the potential loss of Earth mass by oil and coal extraction. The solar system could be modeled with magnetic spheres representing planets rotating in virtual orbits under a given current intensity that keeps them in equilibrated distances with each other based on their respective masses and distances. Small portions of the sphere representing Earth could then be removed gradually to mimic the percentage of the extracted fossil fuels. The outcome could be assessed to see if the percentage of burned oil and coal (calculated here as ~0.000000006 %) would affect the rotating system. However, the removal of 0.000000006 % (~ 6 micrograms) from, for example, a magnetic sphere of 1 Kg may not affect its rotation or its attraction force but with a gradual removal of its mass, we could see at which percentage of the mass removal the system starts to be affected to eventually figure out a critical threshold beyond which the extraction of fossil fuels should be reduced or avoided to avoid any potential serious global consequences.

astrology and environmental sciences would also be required to gather and analyze existing information and provide insight into the following questions: would the rapid and huge extraction of oil and coal result in a real loss of Earth's mass? If so, how much and what would be the part of mass being lost since the discovery of the first oil wells and coal mines till the complete depletion of their respective reserves in the future? What would happen to the mutual attraction force (F) between Earth and other stars, particularly neighboring ones (for example between Earth and moon or between Earth and Sun or other planets)? Are there any geological or biological events that would compensate the potential loss of Earth mass by oil extraction and burning? Would for example the growing human population mass estimated at about 287 million tonnes for adult people (Walpole et al., 2012) play any counterbalancing role to the oil and coal lost parts? One should also wonder what would happen to the Earth's internal structure once the reserves of fossil fuels are completely depleted and what would be the magnitude or consequences on earthquakes when occurring within large regions that have been extensively voided from its 'filling organic matter' (oil).

Finally, the challenge of the intensified uses of fossil fuels is one many other environmental challenges (Davis et al., 2015) that need effective control based on innovative solutions and adaptive management to sustain the non-renewable natural resources and to reduce subsequent risks associated with their depletion at least from the long-term perspective.

References

Dalrymple GB. The age of the Earth in the twentieth century: a problem (mostly) solved. Geological Society, London, Special Publications 2001; 190: 205-221.

Davies GF. Dynamic Earth: Plates, plumes and mantle convection: Cambridge University Press, 1999.

Davis J, O'Grady AP, Dale A, Arthington AH, Gell PA, Driver PD, et al. When trends intersect: The challenge of protecting freshwater ecosystems under multiple land use and hydrological intensification scenarios. Science of The Total Environment 2015; 534: 65-78.

Ellsworth WL. Injection-induced earthquakes. Science 2013; 341: 1225942.

Frohlich C. Two-year survey comparing earthquake activity and injection-well locations in the Barnett Shale, Texas. Proc Natl Acad Sci U S A 2012; 109: 13934-8.

Goff J, Knight J, Sugawara D, Terry JP. Anthropogenic disruption to the seismic driving of beach ridge formation: The Sendai coast, Japan. Sci Total Environ 2015; 544: 18-23.

Grasso J-R. Mechanics of seismic instabilities induced by the recovery of hydrocarbons. pure and applied geophysics 1992; 139: 507-534.

Hays J, Finkel ML, Depledge M, Law A, Shonkoff SB. Considerations for the development of shale gas in the United Kingdom. Sci Total Environ 2015; 512-513: 36-42.

Keranen KM, Savage HM, Abers GA, Cochran ES. Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence. Geology 2013.

Keranen KM, Weingarten M, Abers GA, Bekins BA, Ge S. Induced earthquakes. Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection. Science 2014; 345: 448-51.

Meng Q. Spatial analysis of environment and population at risk of natural gas fracking in the state of Pennsylvania, USA. Science of The Total Environment 2015; 515–516: 198-206.

Nicholson C, Wesson RL. Triggered earthquakes and deep well activities. pure and applied geophysics 1992; 139: 561-578.

Prpich G, Coulon F, Anthony EJ. Review of the scientific evidence to support environmental risk assessment of shale gas development in the UK. Sci Total Environ 2015.

Segall P. Earthquakes triggered by fluid extraction. Geology 1989; 17: 942-946.

Segall P. Induced stresses due to fluid extraction from axisymmetric reservoirs. pure and applied geophysics 1992; 139: 535-560.

Specht A, Guru S, Houghton L, Keniger L, Driver P, Ritchie EG, et al. Data management challenges in analysis and synthesis in the ecosystem sciences. Sci Total Environ 2015; 534: 144-58.

Taverne B. Petroleum, Industry, and Governments: A Study of the Involvement of Industry and Governments in the Production, and Use of Petroleum. Vol 15: Kluwer Law International, 2008.

Trenberth KE, Smith L. The Mass of the Atmosphere: A Constraint on Global Analyses. Journal of Climate 2005; 18: 864-875.

van der Elst NJ, Savage HM, Keranen KM, Abers GA. Enhanced remote earthquake triggering at fluid-injection sites in the midwestern United States. Science 2013; 341: 164-7.

Walpole SC, Prieto-Merino D, Edwards P, Cleland J, Stevens G, Roberts I. The weight of nations: an estimation of adult human biomass. BMC Public Health 2012; 12: 439.

Werner AK, Vink S, Watt K, Jagals P. Environmental health impacts of unconventional natural gas development: a review of the current strength of evidence. Sci Total Environ 2015; 505: 1127-41.

Yerkes RF, Castle RO. Seismicity and faulting attributable to fluid extraction. Engineering Geology 1976; 10: 151-167.

A peer reviewed version is published at: https://doi.org/10.1016/j.scitotenv.2016.01.127

Table 1. Total Oil Production worldwide from 1980 to 2014*

Year	Oil Barrel per day	Oil Barrel per year (365 days)	Oil weight (Kg) per Barrel (1 Barrel=~140 Kg)
2014	93201088	34018397029	4.76258E+12
2013	91014472	32859632846	4,27175E+12
2012	90466487	32737529404	4,25588E+12
2011	88532260	32059502305	4,16774E+12
2010	88099485	31946591792	4,15306E+12
2009	85703404	31006494741	4,03084E+12
2008	86514617	31287562535	4,06738E+12
2007	85130475	30862881629	4,01217E+12
2006	85134828	30890356212	4,01575E+12
2005	85099148	30896112587	4,01649E+12
2004	83402075	30353438358	3,94595E+12
2003	79606389	29056332127	3,77732E+12
2002	77100672	28141745138	3,65843E+12
2001	77672247	28350370199	3,68555E+12
2000	77725453	28369790498	3,68807E+12
1999	74838478	27316044346	3,55109E+12
1998	75680734	27623467855	3,59105E+12
1997	74219760	27090212579	3,52173E+12
1996	71986085	26274920890	3,41574E+12
1995	70304631	25661190425	3,33595E+12
1994	68636649	25052376739	3,25681E+12
1993	67101335	24491987260	3,18396E+12
1992	66552553	24291682002	3,15792E+12
1991	66339100	24213771606	3,14779E+12
1990	66435706	24249032577	3,15237E+12
1989	65518811	23914365960	3,10887E+12
1988	64394518	23503998975	3,05552E+12
1987	62099487	22666312587	2,94662E+12
1986	61533681	22459793718	2,91977E+12
1985	59156363	21592072594	2,80697E+12
1984	59563225	21740577209	2,82628E+12
1983	57927660	21143595915	2,74867E+12
1982	58097931	21205744676	2,75675E+12
1981	60602099	22119766036	2,87557E+12
1980	63987116	23355297504	3,03619E+12
Total (Kg)			1.32317E+14
Total Oil Weight in Trillion Tons			**132** trillion tons

*Source: Energy Information Administration (USA): http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1&cid=ww,&syid=1980&eyid=2015&unit=TBPD Accessed on 20 January 2016.

Table 2. Total Coal Production Worldwide from 1980 to 2012*

Year	Coal Production (Tons)
2012	8687297074
2011	8443802731
2010	7999454814
2009	7601609006
2008	7470959169
2007	7235882783
2006	6965038273
2005	6636340567
2004	6216305801
2003	5813253141
2002	5429459293
2001	5375192780
2000	5137687939
1999	4978418246
1998	5039867508
1997	5069638967
1996	5047504716
1995	4955331148
1994	4872044207
1993	4794646914
1992	4929168603
1991	5018521216
1990	5345000328
1989	5311262411
1988	5234804720
1987	5119885558
1986	5009016691
1985	4891863416
1984	4665243152
1983	4415548925
1982	4379196923
1981	4221808991
1980	4179632567
Total (tons)	1.86491E+11
(Total in trillion tons)	**(~ 0.186 trillion tons)**

*Source: Energy Information Administration (USA): http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=1&pid=7&aid=1&cid=ww,&syid=1980&eyid=2012&unit=TST Accessed on 20 January 2016.