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A dynamic model for liquid fossil fuel production based on gross product/EROI coupling

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Abstract

Since 1940, many attempts to model world oil production have been proposed. These approaches, using increasing complexity, consider the growing and decay of production independently of external, time-varying, causes. It is here proposed to extend the production equation by modelling a dynamic dependency between oil production and its Energy Return On energy Invested (EROI). The model is based on mass and energy conservation and can be applied to all extracted liquid fossil fuels. After comparison with oil extraction and EROI dynamics, it highlights the existence of an external, controlling parameter: the investment rate, which account for the re-investment in newly operated liquid fuel sources. The dynamic of this parameter provides some possible explanations about the progress of the oil shocks and also some possible explanations about the peak prediction issues of the classical Hubbert model. Studying this evolution also suggests an attempt to control the fossil liquid fuel production in order to sustain a globally linear production, starting around 1943: at short time scale (shorter than 30-36 years), the investment rate evolved linearly. However, in order to keep a linearly growing production at long time scale, the investment rate had to evolve exponentially: this was achieved through a piecewise linear control, where the investment rate and its derivative doubled every 30-36 years.

The model also allows to highlight a major issue in liquid fossil fuel production: even if the gross product can be controlled and keeps growing linearly, the net product, which account for the energy delivered by the oil industry to the consumer, can decrease before the gross product peaks, due to the decay of EROI. At this point, the energy benefit of the oil industry will

inevitably decrease and fossil liquid fuel production will slow down. Based on the present model and a sensibility study on its parameters, this tipping point will happen between 2032 and 2039. Net product of fossil liquid fuels could therefore keep growing linearly until this point, where a steep decay is expected. Hence production will be strongly asymmetric regarding the peak, contrary to the prediction suggested by Hubbert's model.

Keywords: Oil production, EROI, dynamic model, investment rate

1 Introduction

2 Models that account for oil production have been published from 1962 [1],
3 with increasing complexity ([2, 3, 4], citing only very few of them). These
4 models rely on a production dynamic with constant parameters. The aim
5 of this study will be to evaluate how the parameters could evolve in time,
6 based on a coupling between oil production (all extracted liquid fuels) and
7 its Energy Return On energy Invested (EROI) at the wellhead, as defined
8 in [5] or [6]. Through this dependency, it is expected to explain why the
9 prediction of peak is always delayed. For simplicity, "all liquid fuels" in the
10 following refers to "all extracted liquid fuels" or "all liquid fossil fuels".

11 The model suggested is based on mass and energy conservation for liquid
12 fuel gross production. It is worth noticing that the structure of the obtained
13 ODE resembles a predator type equation of a Lotka-Volterra set. In this
14 model, production of liquid fuels Q appears to be the EROI predator as the
15 production "feeds" on EROI to grow. It is in line with former use of Lotka-
16 Volterra equations to model dynamic systems in ecology [7] or in economy
17 [8].

18 The article is organised as follow: A first part is dedicated to a presenta-
19 tion of an assumption on a mean global EROI for liquid fuels, suggesting why
20 the model applies to the production of all liquid fossil fuels. It also presents
21 a discussion on a production averaged EROI and its consequence in term of
22 production modelling. The gross product equation is then derived. A fitting
23 of the model parameters based on historical dynamics of oil production and
24 mean EROI is performed, using an inverse method for the investment rate.
25 An analysis of the latter, a forcing parameter, is done, suggesting a control
26 of the investment to keep a linearly growing production. Some possible links
27 between this control and the oil shocks are also presented, suggesting the
28 next oil shock will occur around 2039.

29 A second part is dedicated to studying net liquid fuel production and
30 energy benefit. It highlights the existence of a tipping point between 2032 and
31 2039, where net product will begin to decrease. It suggests two potential
32 limit scenarios for liquid fossil fuel production after this point, which are
33 investigated. This analysis suggests that net energy from fossil liquid fuel to
34 the consumer around 2060-2072, will be that of 1943, just a few years before
35 going down to zero.

36 1. Modelling the interaction between oil production and EROI

37 This section is dedicated to the description of the interactions between
38 production of all liquid fuels Q (in Gbbl) and EROI at the wellhead, as
39 defined in [5] or [6].

40 1.1. An assumption about a global, production averaged, EROI at the well- 41 head

42 The dynamic modelling of all liquid fuels presented in this study requires
43 an EROI function that would be representative of a mean global EROI of all
44 liquid fossil fuels. Considering N liquid fuel sources in the world, $EROI_i$ the
45 EROI of a given source and Q_i its production, mass and energy conservation
46 requires to take $EROI = \frac{1}{Q} \sum_{i=1}^N Q_i \cdot EROI_i$, as it allows to derive a single
47 equation for the production of all liquid fuels, instead of having a set of N
48 equations.

49 Such EROI data seem impossible to gather, since $EROI_i$ are unlikely to
50 be available, therefore it seems adequate to look for some existing model of
51 global, mean EROI, instead of reconstructing EROI based on $EROI_i$ and
52 Q_i . It could however be aggregated by oil categories instead of oil sources,
53 in considering i categories of liquid fuels (considering conventional crude
54 oil, shale oil, off-shore, ultra-deep water oil, etc...). Since fossil liquid fuels
55 production is still nowadays mainly composed of conventional crude oil, using
56 EROI values of conventional oil for an aggregated, global model seems a fair
57 assumption. It would obviously lead to a slight overestimation, since non
58 conventional fossil fuels have lower EROI than conventional [9].

59 The physical model suggested by [10], despite its basic development, fits
60 the requirements presented above. It provides values of EROI that account
61 for the entire crude oil production and presents values at different times which
62 are consistent with actual, measured values of active oil sources. Hence, it
63 will be used in this study, due to the lack of other available, consistent EROI

64 data on a period which is long enough to fit the model parameters with an
65 inverse method. Using the values of [10] to calibrate this model will certainly
66 not allow to estimate precisely the investment rate time evolution, but it
67 should allow to evaluate its global trend over the last decades to estimate its
68 evolution in the forthcoming decade(s).

69 *1.2. A dynamic model for oil production and EROEI evolution*

70 In order to derive the production equation, an energy balance is consid-
71 ered over the whole set of liquid fuel sources, based on a one year time laps
72 ($\Delta t = 1$ year). The ODE is then derived taking $\Delta t \rightarrow dt$. For simplicity,
73 the balance is based on gross product Q_g and the net product Q_n is deduced
74 from Q_g afterwards:

75 On a given year n , a gross product Q_g^n is extracted from the N liquid fuel
76 sources. A fraction k_0 (the investment rate, in year⁻¹) of the associated net
77 product Q_n is used to extract liquid fuels from new sources.

78 The increase in gross product due to this investment is $k_0^n Q_n^n EROI^n \Delta t$,
79 based on the definition of EROI at the wellhead. The net product can
80 be calculated based on the “losses” of the oil industry, as in [10]: From
81 [11, 12, 13, 14], it is possible to estimate the cost of refinery, transportation
82 infrastructures, transportation to consumer and the loss in non-fuel refinery
83 products. Let c_t be the relative cost for all the previously listed “losses”.
84 One gets $c_t = 0.54$, according to [12], Table 3. Energy conservation implies
85 that the remaining part of the gross product is composed of the extrac-
86 tion/production cost plus the net product (or net energy to the consumer),
87 hence:

$$Q_g = Q_n + Q_{ext} + Q_t, \quad (1)$$

88 with Q_g the gross product, Q_n the net product, Q_{ext} the extraction/production
89 cost and Q_t the previously listed costs, with $Q_t = c_t Q_g$. According to EROI
90 definition, $Q_{ext} = Q_g / EROI$, hence:

$$Q_n = \frac{EROI(1 - c_t) - 1}{EROI} Q_g. \quad (2)$$

91 Therefore the increase in gross product at the next time laps is $k_0^n Q_g^n (EROI^n (1 -$
92 $c_t) - 1) \Delta t$.

93 During the same time laps, the producing fuel sources show a decline
94 which follows the model described in Sorrell [15]: Considering k_1 the mean
95 oil source decline rate (in year⁻¹), the associate decrease in production is
96 equal to $Q_g^{n+1} - Q_g^n = -k_1 \cdot \Delta t$.

97 Both phenomena occur at the same time, during the same time laps. Since
 98 they are linear, it is possible to use superimposition to get: $Q_g^{n+1} - Q_g^n =$
 99 $Q_g^n[k_0^n(EROI^n(1 - c_t) - 1) - k_1]\Delta t$. Taking $\Delta t \rightarrow dt$ leads to:

$$\dot{Q}_g = k_0 Q_g (EROI(1 - c_t) - 1) - k_1 Q_g. \quad (3)$$

100 1.3. Fitting the model parameters on the period 1943-2018

101 Since the study [10] provides an EROI dynamic from 1930, k_0 could be
 102 investigated on the period 1930-2018, for which both EROI and Q_g dynamics
 103 are available. The analysis however focus on a period which begins in 1943.
 104 Indeed, the production curve shows a clear change of production rate in 1943.
 105 From that time, the gross product is mostly linear, with several overshots
 106 and undershots. Using Hubbert's logistic fit as in [16], this part of the curve
 107 is very close from being linear. Also, a linear fit of the gross product on the
 108 period 1943-2019 shows a determination coefficient higher than 0.95. These
 109 remarks suggest that the business as usual of the oil industry began around
 110 1943. This is why the investment rate is investigated on the period 1943-2019,
 111 in order to evaluate how this business as usual is sustained.

112 k_1 represents the oil sources mean decline rate. This parameter should be
 113 extracted from experimental measurements, using inverse methods. Based
 114 on the results of [15], the mean value lies in the range 4.1 – 6.7% but is
 115 increasing with the exploitation of new non-conventional sources. Therefore,
 116 k_1 is set equal to 6% (a mean value based on previous remark) and k_0 can
 117 be fitted.

118 Now, based on Eq.(3), setting a value for k_1 , it is possible to plot k_0
 119 dynamic, based on historical data for Q_g and a model for EROI:

$$k_0 = \frac{\dot{Q}_g}{Q_g(EROI(1 - c_t) - 1)} + \frac{k_1}{EROI(1 - c_t) - 1}. \quad (4)$$

120 The oil production data is extracted from [16, 17]. As stated in section
 121 1.1, the EROI dataset is taken from [10], considering both the optimistic and
 122 the pessimistic fit. The analysis is performed on the period 1943-2019 using
 123 a three-year averaging on Q_g and a second order upwind method to calculate
 124 Q_g derivative.

125 1.4. Studying the investment rate

126 1.4.1. History of the investment rate

127 The investment rate can be evaluated through the value of k_0 , which lies in
 128 the range $[0; 1[$. It is nevertheless suggested to study $k_{eff} = k_0 \frac{EROI(1-c_t)-1}{EROI} =$

129 $k_0 \frac{Q_n}{Q_g}$ instead of k_0 , for function fitting requirements. The parameter k_{eff} ,
130 which represents the forcing of the system is plot over time in Fig.1. Its
131 analysis provides some possible characteristics of the oil extraction strategy,
132 which are presented below.

133 On the period 1943-1968, k_{eff} is relatively linear, as Fig.1 shows. In
134 1969, k_{eff} begins to decrease, most likely due to the geopolitical event that
135 led to the first oil shock. This shock is then responsible for an instantaneous
136 drop of k_{eff} in 1973, but k_{eff} is kept constant just after the shock, hence
137 no clear disruption appears in oil production. Due to the mathematical
138 structure of the model, a constant k_{eff} is not sufficient to sustain a linearly
139 growing production for more than a few years. This is likely to be the cause
140 of the second oil shock, which corresponds to another, longer drop of k_{eff} .
141 Contrary to the first shock, it creates a disruption both in investment rate
142 and oil production from 1979 to 1985, where investment is way under its
143 mean value, as observed in Fig.1. It is therefore suggested here that the first
144 shock is mainly geopolitical, whereas the second one is mainly economic.

145 On the period 1943-1978, k_{eff} is mostly linear, despite the first shock.
146 The solid line fits the data with a mean relative error equal to 13%.

147 After the second shock, k_{eff} seems to evolve (globally) linearly, with raises
148 and plateaus during the period 1986-2006. The dashed line fits the data with
149 a mean relative error of less than 5%. Compared to the period 1943-1978,
150 one can see that the slope has roughly doubled. This behaviour allows Q_g to
151 grow linearly in time again. The plateaus of k_{eff} are responsible every time
152 for a slow damping of Q_g , which corresponds to past predictions of a nearby
153 peak, using Hubbert's curves. This phenomenon leads every time to an
154 economical recession and a raise in oil price (this can be shown in comparing
155 Fig.1 with an oil price chart), at the moment where the oil industry needs
156 to increase its investment to keep k_{eff} close to the behavior that ensure a
157 linearly growing Q_g . The following assumption is suggested to explain the
158 origin of this raise/plateaus dynamic: With time, the production of an oil
159 source eventually decreases, meaning that exploration is firstly needed to
160 extract more oil. It means that if exploration does not suggests new sources
161 to exploit, the production stagnates because it is not possible to invest in
162 new sources, therefore k_{eff} is constant or slightly decreasing. When new
163 sources become available, the investment rate can quickly increase until the
164 new sources become less available and then exploration has to start again.

165 In 2007-2008, another oil shock happened, which again caused a sudden

166 drop of k_{eff} . From this point, k_{eff} seems to be linear again, but again the
 167 slope has doubled in comparison to the previous period. It can be seen in
 168 Fig.1, where the dotted line fits the data with a mean relative error equal to
 169 7%.

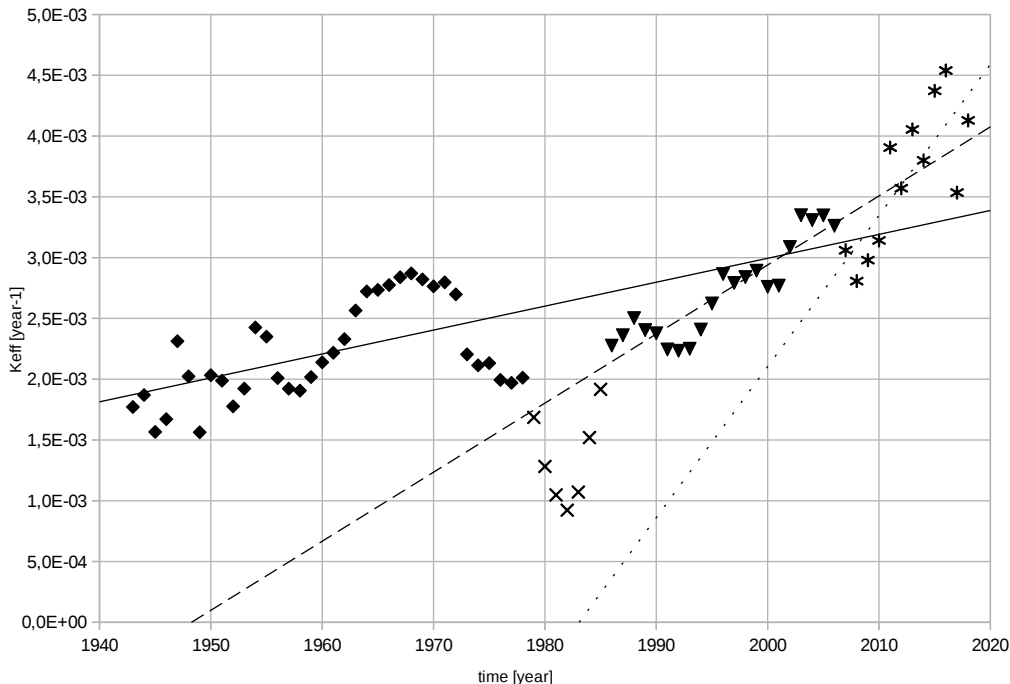


Figure 1: k_{eff} dynamic on the period 1943-2018. Symbols are measured values: diamonds on the period 1943-1978, crosses on the period 1979-1985, triangles on the period 1986-2006 and stars on the period 2007-2019. Lines are linear fits: solid line on the period 1943-1978, dashed line on the period 1986-2006 and dotted line on the period 2007-2019.

170 1.4.2. The limit of a linear dynamic

171 Studying k_{eff} at long time scale shows the real dependency of Q_g on
 172 k_{eff} : in order to keep a linearly growing Q_g , k_{eff} should follow a behavior
 173 close to an exponential. This corresponds to the description of the previous
 174 section: A piecewise linear behavior where the slope doubles at fixed time
 175 interval. It means that in order to sustain a linear production dynamic, k_{eff}
 176 should follow $k_{eff} \sim \exp(t/\tau)$ with $\tau = 48 \pm 4$ year, depending on the EROI
 177 dynamic (optimistic or pessimistic) that is used to fit τ . Fig.2 shows k_{eff}

178 on a period 1943-2040 along with a projection based on a linearly increasing
 179 production and the exponential fit. It means that the investment rate and
 180 its derivative has to double every $\Delta t_{shock} = \tau \ln(2) = 33 \pm 3$ year, which fit
 181 both the time between the beginning of the business as usual in 1943 and
 182 the major disruption in oil production in 1979, and the time between this
 183 disruption and the oil shock of 2007-2008. It suggests this is the main reason
 184 why oil shocks have to happen. It would mean that the next oil shock will
 happen around 2040.

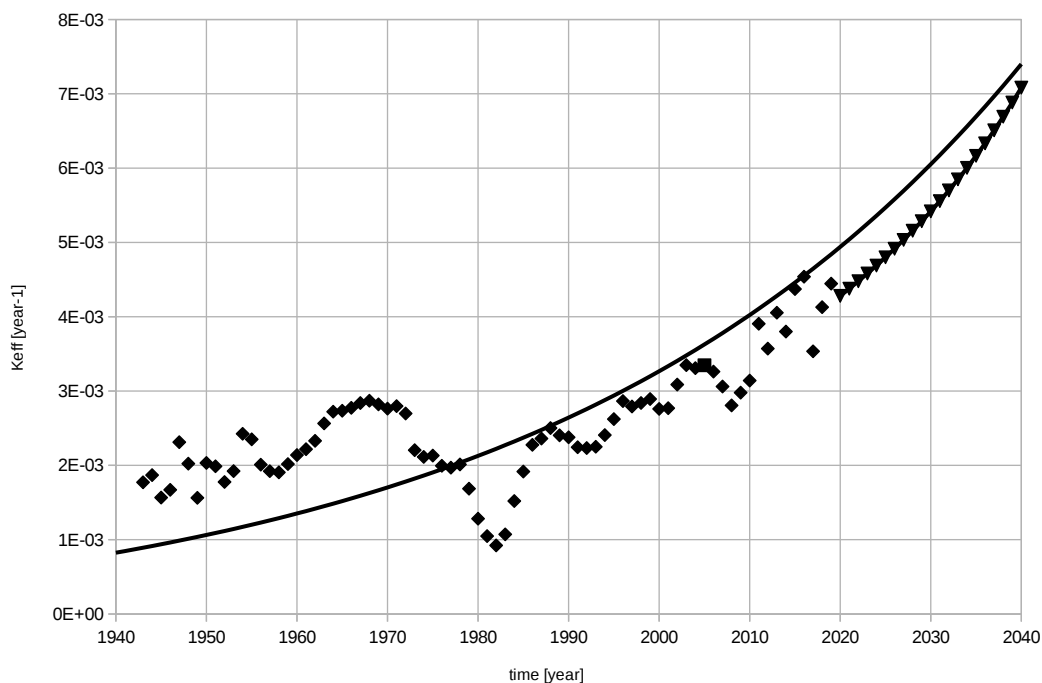


Figure 2: k_{eff} dynamic on the period 1943-2040. Diamonds are measured values on the period 1943-2019 and triangles are projected values on the period 2020-2040. The solid line is the exponential fit.

185

186 2. Analysis of net production and energy benefit

187 In order to evaluate the future dynamic of oil extraction based on this
 188 scenario, numerical simulations are done with a 0.5 year time step and a

189 Runge-Kutta 4 method, starting in 2020, after a numerical validation on the
190 period 1930-2019. The results presented here are based on historical data
191 for the period 1943-2019 and based on numerical simulations for the period
192 2020-2080.

193 *2.1. The tipping point*

194 In order to evaluate how long the business as usual of the oil industry can
195 be sustained, it is suggested to study the absolute energy benefit of the oil
196 industry, which reads $\epsilon_A = (1 - k_0)Q_n$. As observed in Fig.3, where ϵ_A has
197 been normalized by its maximum value, it reaches this maximum between
198 2032 and 2039, at EROI=9-10. This is in line with [12, 9] who suggest the
199 energy cliff happens at EROI=10. It is the point at which industrial societies
200 cannot keep growing the way it used to. When ϵ_A begins to decrease, the
201 oil industry cannot grow anymore, even with a gross product that keeps
202 growing linearly. It suggests the oil business will not be viable anymore
203 as it will get a decreasing benefit while requiring an increasing investment.
204 Besides, k_{eff} fits an exponential function, but the investment rate k_0 is also
205 exponential only as long as Q_n/Q_g is constant. From that point, the effect of
206 Q_n/Q_g cannot be neglected anymore (i.e. the energy cliff has been reached),
207 therefore Δt_{shock} is not constant anymore and k_0 would have to double in
208 about 16 years, then 12,6 and so on. As the oil industry can take a few years
209 to recover from a shock, it might be impossible to recover from a shock when
210 the next one happens. Such scenario is therefore physically possible, yet it
211 seems economically impossible.

212 It is most likely that investment will go to other energy sources of higher
213 EROI. Nevertheless, renewables with EROI higher than 10 need their whole
214 lifespan to generate the energy after the energy investment is done. It mean
215 that the “classical” return on investment is faster with oil than with renew-
216 able, what might keep investing in oil to sustain a minimum level of energy
217 if the development of renewable is not sufficient when this point is reached.

218 Two extreme scenarios are investigated, based on this analysis. The first
219 one corresponds to $k_0 = 0$ after the tipping point (a transition scenario) and
220 the second corresponds to a sustained linear gross product until $Q_n/Q_g = 0$
221 (a business as usual scenario).

222 *2.2. Remaining net energy from liquid fossil fuel*

223 In order to evaluate the net amount of energy that can be delivered by
224 liquid fossil fuel, the net product is investigated. The future net product

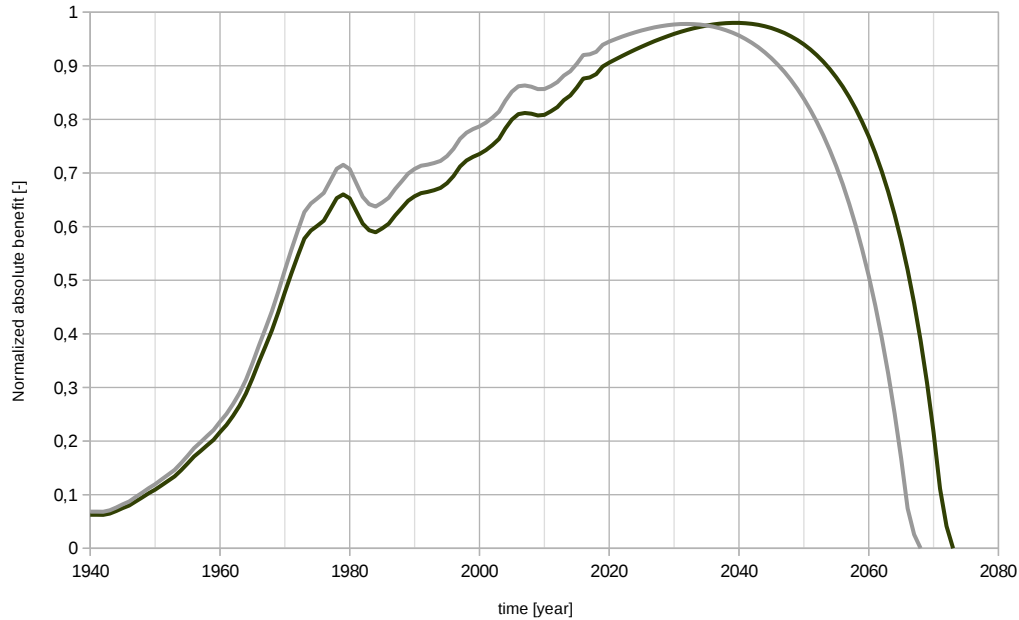


Figure 3: Normalized absolute energy benefit, for both optimistic (black line) and pessimistic (grey line) EROI dynamics

225 trend is firstly compared to past and nowadays trends. The total amount
 226 (i.e. integral or cumulated) of remaining net energy to the consumer is also
 227 compared to the net energy already used by our industrial societies and finally
 228 a point to point comparison is done. In every case, a range is suggested, based
 229 on the two proposed scenarios and the two EROI dynamics used in this study.

230 Fig.4 shows the net energy from oil on the period 1943-2080. The solid
 231 lines represent the business as usual scenario and the dotted lines represent
 232 the transition scenario. One can see that the trend will remain almost the
 233 same from 2021 to the tipping point as it was on the period 1985-2020,
 234 suggesting the available energy evolution after the tipping point might be
 235 very abrupt (i.e. “we can’t see it coming based on the evolution of net
 236 available energy”). If the transition scenario happens, our industrial societies
 237 might struggle to adapt to such a steep drop of available energy. If the
 238 business as usual can be sustained for a few years, a plateau of net energy
 239 will occur before the drop. Either way, the slope of the drop is roughly twice
 240 the inverse of that of the rise.

241 Depending on the scenario and the EROI dynamic, the remaining net en-
242 ergy from 2021 to the end of oil extraction is in the range [320-680]Gbbbl, with
243 540Gbbbl and 680Gbbbl for the business as usual scenario and with 320Gbbbl
244 and 470Gbbbl for the transition scenario. It corresponds to the net energy
245 from 1930 or 1995 to 2021 (1930 or 1980 to 2021 for business as usual and
246 1970 or 1995 to 2021 for transition). Either way, it means that the mid-point
247 of net energy from oil has already been past. Most likely, the remaining net
248 energy from oil is less than what we already used from the first oil shock
249 until 2020.

250 Fig.4 also highlights that the net available energy from oil in 2040-2050
251 will be that of 1970 with the transition scenario (in 2060-2068 with the busi-
252 ness as usual scenario) and in 2055-2063 it will be that of 1943 with the
253 transition scenario (in 2066-2072 with the business as usual scenario). It fi-
254 nally suggests the end of oil as an energy source around 2068-2072, whatever
255 the scenario.

256 Conclusion

257 This study proposes a production averaged model which allow to inves-
258 tigate the extraction dynamic of fossil liquid fuels. This dynamic follows a
259 typical Lotka-Volterra equation. An investigation of its parameter dynamic,
260 based on an inverse method, along with numerical simulations to forecast
261 production, allows to highlight the following:

- 262 • A parameter controlled by the oil industry, the investment rate, drives
263 the production dynamic.
- 264 • This rate has to evolve exponentially to keep the production growing
265 linearly: the investment rate and its derivative roughly doubles every
266 33 ± 3 year.
- 267 • This behavior seems to be the explanation for oil shocks, hence the
268 next one will occur around 2039.
- 269 • It shows the existence of a tipping point between 2032 and 2039, at
270 EROI=9-10, before the peak of gross product, where the oil industry
271 cannot grow anymore. It corresponds to the energy cliff. From this
272 point, investment might switch to other energy sources with higher

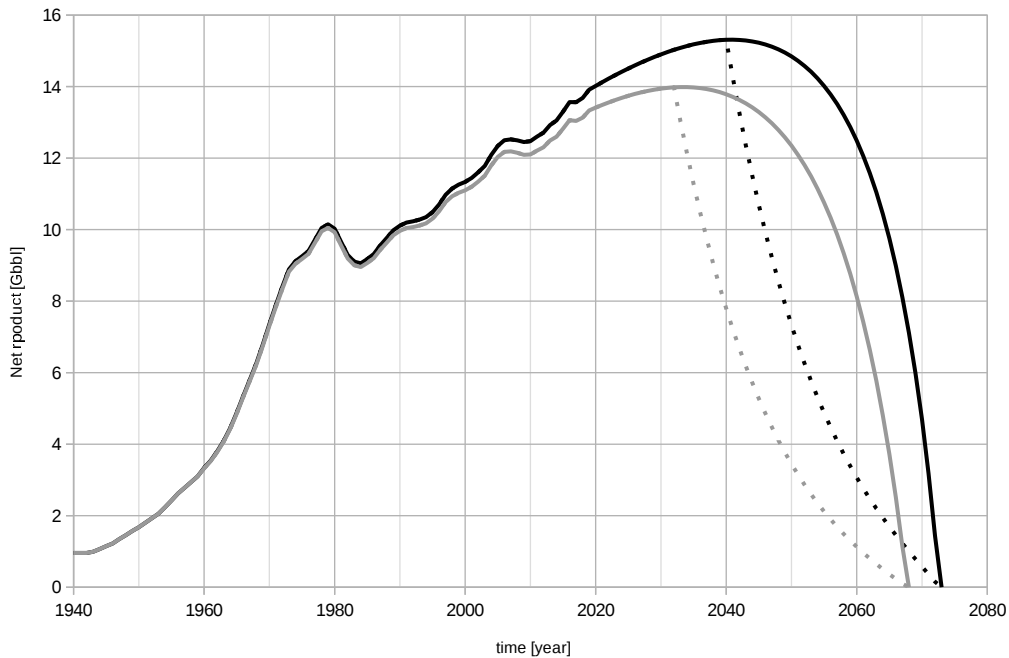


Figure 4: Net product: Energy delivered to the consumer, for both optimistic (black line) and pessimistic (grey line) EROI dynamics. The solid line is the business as usual scenario and the dotted line is the transition scenario.

273 EROI. If this change of investment happens immediately after the tip-
 274 ping point, an extremely fast decay of the net product is expected.
 275 Otherwise a small plateau is expected before a fast decay.

- 276 • Either way, the net product of liquid fossil fuel will be zero around
 277 2068-2072.

278 Finally, the physical bases and the mathematical form of the model sug-
 279 gests this method applies to study the dynamics of other energy source pro-
 280 duction, such as gas, coal, nuclear or renewable.

281 References

- 282 [1] M. Hubbert, Energy resources: A report to the Committee on Natu-
 283 ral Resources of the National Academy of Sciences–National Research
 284 Council (1962).

- 285 [2] A. Bartlett, An analysis of U.S. and world oil production patterns using
286 Hubbert-style curves, *Mathematical Geology* 1 (2000).
- 287 [3] A. Cavallo, Predicting the peak in world oil production, *Natural*
288 *Ressources Research* 3 (2002).
- 289 [4] R. Duncan, Three world oil forecasts predict peak oil production, *Oil*
290 *and gas journal* 14 (2003).
- 291 [5] C. Cleveland, Net energy from extraction of oil and gas in the United
292 States, *Energy* (2004) 1–14.
- 293 [6] D. Murphy, A. Hall, Year in review-EROI or energy return on (energy)
294 invested, *Annals of the new york academy of sciences* (2010) 102–118.
- 295 [7] H. Freedman, Deterministic Mathematical models in population Ecol-
296 ogy.
- 297 [8] R. Goodwin, A Growth Cycle, paper presented at the First World
298 Congress of the Econometric Society (1965).
- 299 [9] D. Murphy, The implicits of the declining energy return on invested of
300 oil production, *Philos. Trans. R. Soc. Lond. A: Math. Phys. Eng. Sci.*
301 (2014).
- 302 [10] A. Lamorlette, A semi-empirical model for conventional crude oil energy
303 return on energy invested, *archives HAL* (2021) hal-03307809.
- 304 [11] Annual Energy Review, International Energy Agency, World Energy
305 Investment (2009).
- 306 [12] A. Hall, S. Balogh, D. Murphy, What is the minimum EROI that a
307 sustainable society must have?, *Energies* (2009) 25–47.
- 308 [13] R. Mudge, D. Kulash, D. Bodde, Energy use in Freight Transportation,
309 Congressional Budget Office U.S. Congress (1982).
- 310 [14] A. Szklo, R. Schaeffer, Fuel specification, energy consumption and CO2
311 emmision in oil refineries, *Energy* (2007) 1075–1092.

- 312 [15] S. Sorrell, J. Speirs, R. Bentley, R. Miller, E. Thompson, Shaping the
313 global oil peak: A review of the evidence on field sizes, reserve growth,
314 decline rates and depletion rates, *Energy* 37 (2012) 709 – 724. 7th
315 Biennial International Workshop “Advances in Energy Studies”.
- 316 [16] J. Rodrigue, C. Comtois, B. Slack, *The geography of transport systems*,
317 2016.
- 318 [17] 2020. <https://transportgeography.org>.