1 What Is the Problem? Men and Joules

The time of the finite world begins
Paul Valéry (1945)

Let us start summarizing our current situation. Our civilization relies on fossil fuels. Like Rome's prosperity was fueled by conquests ([1], see Sect. 10.1), ours is fueled by fossil fuels. Because these are *non*-renewable energy sources, sooner or later they will *necessarily* be exhausted. You cannot drink infinitely from a bottle that does not refill. It is sobering to think that on the timescale of humanity, let alone the earth timescale, the fossil fuel era will just have been a few hundred years long parenthesis, like the one pictured on Fig. 1.1. The question, for us in the parenthesis, is to decide what will happen next. It is urgent to start looking for alternative energy sources. How urgent? Regarding oil, we have burnt roughly half of what was easy to extract, and worldwide production should flatten by now before it starts decreasing irrevocably (see Chap. 3).

Yet, there is a lot of gas, coal, and unconventional oil left.[1] Can we thus quietly search energetic alternatives while burning every single gram of fossil resources? No, because of this famous "climate change." Burning fossil fuels since the beginning of the industrial revolution has already significantly heated the planet. And climate scientists are warning: burning all of the available fossil fuels would result in a tremendous global warming (see Sect. 4.5). There is therefore no time to wait, as history seems to teach that leaving behind some habits requires you have something to replace them (see part III).

A little account of the love story between humanity and energy, men and Joules, is indeed useful to realize how staggering our energy dependence is. Suppose you

[1] "Conventional" oil is the oil we have been hearing about from the last 200 years, like crude oil. It is liquid and can be extracted drilling a well. Unconventional oil is a fossil resource demanding much more treatment for its exploitation, like tar sands or shale oil. See Sect. 7.1 or www.iea.org/aboutus/faqs/oil/.

A. Bret, *The Energy-Climate Continuum*, DOI: 10.1007/978-3-319-07920-2_1

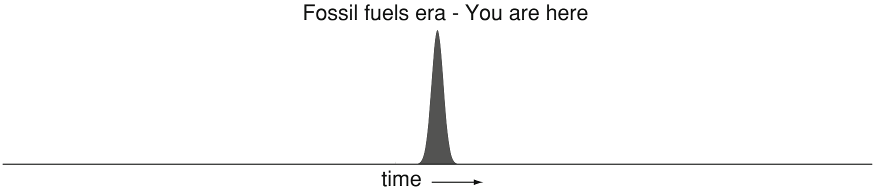

Fig. 1.1 On the timescale of humanity, the fossil fuel era will just have been a few 100 years long parenthesis

are a cave man or woman living way before any energy source was harnessed. You can only rely on your own strength. You need some 2,000 kilocalories per day to survive. Calories are but one more unit of energy, and 1 kilocalories are 4.18×10^3 J (see Appendix A for more on energy units and some explanations on numbers like 10^x). Then, if you ingest an extra 2,000 kilocalories to work, you can give away daily $2{,}000 \times 4.18 \times 10^3 = 8.36 \times 10^6$ J, that is, about 8 mega-joules (MJ). As your muscles are not perfect machines, they require about 4 J of physiological chemical energy to deliver 1 J of mechanical work.[2] You are thus left with 2 MJ a day,[3] which can let you, for example, carry a 2 tons load 100 m up.[4]

What if you want more? You can domesticate animals and have them work for you. For cattle and horse, that was done around 8000 and 3500 BC, respectively [4,5]. Searching for even more, you can use wind to sail. The earliest evidences for such technique date back to 5000 BC [6]. Wind can also power a windmill, evidences of which have been found from the third century BC [7]. Each time you find a new source of energy, you quickly get used to it and look soon for the next one. The next step was to harness people. This is called slavery. Evidences for it has been found in Egypt as soon as the third millennium BC ([8, p. 28]), and the Sumerian Code of Ur-Nammu, dated around 2100 BC, already includes regulations such as "If a slave marries a slave, and that slave is set free, he does not leave the household".[5]

Until the eighteenth century, this is all we had: ourselves, animals, wind, and slaves. We should sum to the list the water wheel, known from the fourth century BC [9], and biomass fuels (wood, crop residues, food wastes…) mainly used as a heat source ([10, p. 26]). Then, came James Watt with his steam engine in 1769. As simple as it sounds, this is truly revolutionary for it allows you to convert heat into *work*. Fire had been known for nearly 800,000 years [11]. But without the steam engine, you

[2] See Wikipedia on "Muscle Efficiency."

[3] This is an average power output of 23 W. The best bikers in the world can deliver some 400 W on average during a few hours [2] Assuming they do so for 5 h, and rest for the rest of the day, these are more than 7 MJ of mechanical work produced daily. But they are top athletes, and they do not sustain such exercise all year long. During the final of the 100 m at the 2009 World Championships in Berlin, Usain Bolt may have delivered more than 2,600 W around the first second of his race. But that lasted only for a flash [3].

[4] Just compute Energy $=$ mass$\times$height$\times$acceleration of gravity, with mass $= 2{,}000$ kg, height $=$ 100 m and acceleration of gravity $= 9.8$ ms^{-2}.

[5] See http://en.wikipedia.org/wiki/Code_of_Ur-Nammu.

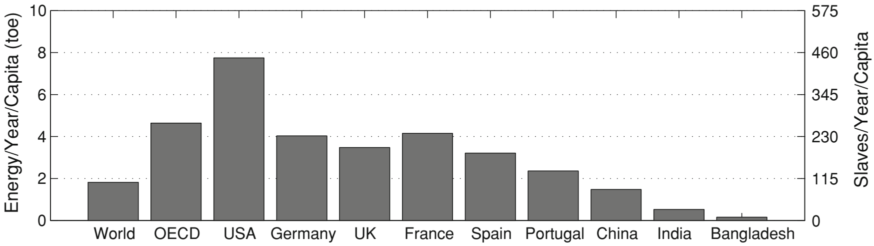

Fig. 1.2 Yearly energy consumption per capita for various countries, or group of countries. *Left scale* In tons oil equivalent (toe). *Right scale* In "energy slaves" equivalent, accounting for 2 MJ/day for a slave. *Source* International Energy Agency, Key World Statistics 2010 [14]

cannot do anything with fire but heating or burning. Without the steam engine, fire is useless to power a plow, a stagecoach, or a boat. The invention of the steam engine eventually amounts to harnessing chemistry. Suddenly, it becomes possible to use any kind of exothermic chemical reactions such as *combustion* reactions, to power whatever you need. As soon as you have heat, whether it be by burning wood, coal, gas, or oil, you can have work.[6] This invention triggered the industrial revolution.

As already stated, once you find a new source of energy, you quickly get used to it and look for more. This is exactly what happened during the last 200 years, as our fossil fuels consumption has been steadily growing. At the beginning of the nineteenth century, fossil fuel consumption, exclusively coal at the time, was 3.5×10^{17} J a year ([10, p. 155]). In 2010, it was 3.6×10^{20} J [14]. A thousandfold increase in 200 years when the world population has only been multiplied by 7 during the same period [15, 16].

Figure 1.2 displays the 2010 energy consumption per capita for various countries, or group of countries. In order to grasp these numbers, we follow Richard Buckminster Fuller who coined the term "energy slaves" in 1940 [17] (see also more recently [18–20]). The left scale shows the numbers in "tons oil equivalent" (toe). The right scale translates the amounts of oil burnt to the number of "energy slaves" required to deliver an equivalent energy. On average, each world citizen consumes a little less than 2 toe of energy per year, this is, 84 giga-joules (GJ).[7] Considering a slave would deliver 2 MJ a day, 84 GJ represent one year of work of 115 slaves! Clearly, numbers vary greatly from nearly 445 in the US to 9 in Bangladesh, but the result is appalling. If each member of an OECD country had to forget about his 4.6 toe of fossil fuel energy, he would require the "service" of 266 energy slaves.[8]

Historians tell us Louis XIV (1638–1715) had about 4,000 servants running the Palace of Versailles [21]. Each one of us in the Western world benefits from a signif-

[6] Oil ([12, p. 23]), coal ([10, p. 28]), and gas ([13, p. 41]) were all exploited way before the industrial revolution. Yet, they needed the steam engine to trigger it.

[7] See the oil/energy equivalence in Appendix A.

[8] The numbers vary according to how you compute the "energy slave" unit. But the result is always surprising.

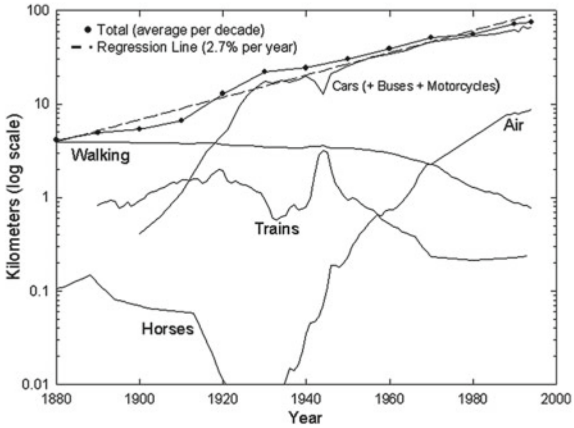

Fig. 1.3 US passenger travel per capita per day by all modes. From [22]

icant fraction of one of the most magnificent king of France privileges. Just imagine Louis XIV home alone in Versailles, without his servants. This gives an idea of how much we now rely on external sources of energy.

Another graph is very interesting in this respect. Figure 1.3 shows the evolution of US passengers daily travel per capita. Back in 1880, a US citizen would on average walk 4 km a day and ride 100 m. By the beginning of the twentieth century, Henry Ford introduced his Model T claiming "I will build a motor car for the great multitude" ([23, p. 73]) and since 1920, more distance is covered daily by car than by walking. Although train experienced a boost during the Second World War, it never surpassed walking. Finally, flying has been preceding walking since 1970. All in all, it has been nearly 100 years since the number one conveyance requires a lot of extra energy. It means the US, with at least the rest of the OECD countries (even if the numbers would change), are no longer adapted to the sole human scale. Whether we commute, shop, visit family and friends, go to the doctor or on vacations, we no longer rely on our own legs. Even the dishes on our table traveled thousands of kilometers to get there.[9]

The historian Ian Morris chooses "energy capture" as the first trait to measure social development throughout history[10] ([26, p. 147]), and Kenneth Pomerantz, another prominent historian, definitely agrees [27]. It is therefore no surprise that among the top ten worldwide companies by revenue in 2012, 8 belonged to the energy industry.[11] Our present world is fundamentally designed to function with an army of slaves serving each one of us. So, if you free them too quickly, you cannot expect anything but chaos.

---

9 The term "food-miles" was coined to measure this. See [24,25].

10 Morris defines social development as "a group's ability to master its physical and intellectual environment to get things done" ([26, p. 144]).

11 *CNN Money* 2012 ranking.

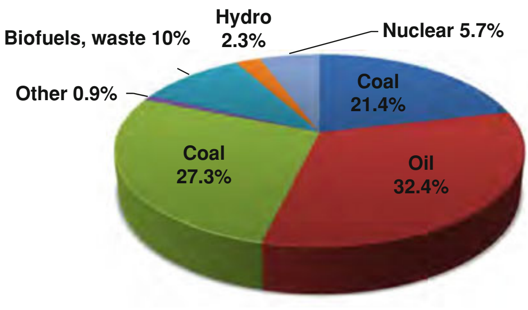

Fig. 1.4 Global primary energy supply by kind of fuel in 2010. "Other" includes geothermal, solar, wind, heat, etc. The total amounts to 12,717 Mtoe. From [14]

Who are these slaves, for now? Figure 1.4 shows a snapshot of the global primary energy supply by kind of fuel, in 2010. A total of 12,717 million toe were produced. Nothing else than 7 billion people burning 1.8 toe each. Fossil fuels that should be left behind, delivered 81.1 % of the total.

Noteworthily, this book deals exclusively with fossil fuels as energy sources. Yet, our addiction also relates to a host of *non*-energetic uses of these substances. Plastic, for example, is made from them. In 2012, 288 megatons of it were produced worldwide.[12] Considering crudely that only oil was used and that it takes 1 kg of oil to generate 1 kg of plastic, we find about 1.5 billion barrels were dedicated to plastic production alone in 2012. This is about 5 % of the overall oil production for the same year.[13] Leaving fossil fuels behind is not just an energy challenge.

The big problem is that there is so far no easy solution. This is, as easy as fossil fuels. Later on in the book, we shall look at the ways you can store energy (Chap. 5) and find out oil is incredibly efficient at it. The reason why it is difficult to phase out is precisely because it is the most efficient form of encapsulating energy. Just dig at the right place, and you collect an incredibly energetic substance nature has done for you. And on the top of it, it is almost free. At $120 per barrel (160 L), the 42 MJ of 1 L are yours for less than $1. Cheaper than most mineral waters. So even if there were no climate issues shortening the delay, finding alternative energy sources to replace fossil fuels would be a tremendous task.

References

1. J. Tainter, *The Collapse of Complex Societies. New Studies in Archaeology* (Cambridge University Press, Cambridge, 1990)
2. B.L. Hannas, J.E. Goff, Model of the 2003 Tour de France. American J. Phys. **72**, 575 (2004)
3. J.J. Hernández Gómez, V. Marquina, R.W. Gómez, On the performance of Usain Bolt in the 100m sprint. European J. Phys. **34**(5), 1227 (2013)

[12] See http://plasticseurope.org.

[13] See Fig. 3.1. This order of magnitude fits the real numbers ([28, p. 60]).

4. R.T. Loftus, D.E. MacHugh, D.G. Bradley, P.M. Sharp, P. Cunningham, Evidence for two independent domestications of cattle. Proc. Natl. Acad. Sci. **91**, 2757–2761 (1994)
5. A.K. Outram, N.A. Stear, R. Bendrey, S. Olsen, A. Kasparov, V. Zaibert, N. Thorpe, R.P. Evershed, The earliest horse harnessing and milking. Science **323**, 1332 (2009)
6. R. Carter, Boat remains and maritime trade in the Persian Gulf during the sixth and fifth millennia BC. Antiquity **80**(307), 52–63 (2006)
7. M.J.T. Lewis, The Greeks and the early windmill. Hist. Technol. **15**, 141–189 (1993)
8. O. Pétré-Grenouilleau, *Les traites négrières: Essai d'histoire globale* (Gallimard, Collection Folio. Histoire, 2006)
9. Ö. Wikander, *Handbook of Ancient Water Technology* (Technology and Change in History, Brill, 2000)
10. V. Smil, *Energy Transitions: History, Requirements, Prospects* (Praeger, New York, 2010)
11. N. Goren-Inbar, N. Alperson, M.E. Kislev, O. Simchoni, Y. Mordechai, Y. Melamed, A. Ben-Nun, E. Werker, Evidence of hominin control of fire at gesher benot ya'aqov, Israel. Science **304**(5671), 725–727 (2004)
12. D. Yergin, *The prize: the Epic Quest for Oil, Money, and Power* (Simon & Schuster, New York, 1991)
13. D.C. Wright, *The History of China* (Greenwood Histories of the Modern Nations, Greenwood, 2011)
14. International Energy Agency. Key world energy statistics. International Energy Agency (2012)
15. M. Kremer, Population growth and technological change: one million BC to 1990. Q. J. Econ. **108**(3), 681716 (1993)
16. C. McEvedy, R. Jones, *Atlas of World Population History* (Penguin, Harmondsworth, 1978)
17. R.B. Fuller, The US industrialization. Fortune Mag. **XXI**(2), 57 (1940)
18. J.R. McNeill, *Something New Under the Sun: An Environmental History of the Twentieth-Century World* (The Global Century Series. W. W, Norton, 2001)
19. J.M. Jancovici and A. Grandjean. *Le plein s'il vous plaît !: La solution au problème de l'énergie*. Collection Points. Série Sciences. Éd. du Seuil, (2007)
20. J.-F. Mouhot, Past connections and present similarities in slave ownership and fossil fuel usage. Clim. Change **105**, 329–355 (2011)
21. A. Rambaud. *Petite histoire de la civilisation française depuis les origines jusqu'à nos jours, à l'usage des classes élémentaires: Leçons-résumés-questionnaires-420 gravures*. A. Colin (1896)
22. J.H. Ausubel, C. Marchetti., P. S. Meyer. Toward green mobility: the evolution of transport. European Rev. **6**(2), 137–156 (1998)
23. H. Ford, S. Crowther, *My Life and Work. Library of American Civilization* (Doubleday, Page, New York, 1922)
24. L. Christopher, H. Weber, S. Matthews, Food-miles and the relative climate impacts of food choices in the United States. Environ. Sci. Technol **42**(10), 3508–3513 (2008)
25. G. Lawrence, K. Lyons, T. Wallington, *Food Security* (Nutrition and Sustainability, Taylor & Francis, 2009)
26. I. Morris, *Why the West Rules—for Now: The Patterns of History, and What They Reveal About the Future* (Profile Books, New York, 2010)
27. K. Pomerantz, How big should historians think? A review essay on why the west rules—for now by Ian Morris. Cliodynamics **2**(2), 304 (2011)
28. S. Freinkel, *Plastic: A Toxic Love Story* (Houghton Mifflin Harcourt, Boston, 2011)

http://www.springer.com/978-3-319-07919-6

The Energy-Climate Continuum
Lessons from Basic Science and History
Bret, A.
2014, XII, 169 p. 49 illus., 33 illus. in color., Hardcover
ISBN: 978-3-319-07919-6