CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 10, No.1, March 2026, 19-69

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Managing risk in the Forever Society - a primer

Laurenc L. DEVITA

Research Centre for System Risk Management, USA

Received: 21.12.2025, Revised: 21.02.2026, Accepted: 23.03.2026
doi: http://10.29015/cerem.1047

Aim: To describe a methodology for looking at human actions in the context of a sustainable society.

Research methods: Reviewed data on the health of the ecosphere, and a consideration of efforts to describe and mediate ecosystem degradation.

Conclusions: A methodology is needed to context the complex global system and it's subordinate and constituent systems with consequences for violating sustainable goals.

Originality / value of the article: It provides a means of linearizing the complexity of systems which uses the carbon dioxide molecule as the base unit of analysis, and locates humans within the context of resource use. Using the concept of Energy Return on Energy Investment to evaluate variables simplifies analysis.

Implications of the research: A global effort to consider the basin of sustainability is needed.

Limitations of the research: This paper is a primer, and uses a hypothetical project to explore the methodology and concepts. It uses commonly available data to discuss the global system. A next step would be to use the methodology with data on an actual project or social system.

Keywords: Energy Return on Energy Investment; Maximum Power Principle; surplus of nature; basin of sustainability; sustainability debt; ecosystem value; externalities; carbon dioxide; carbon cost.
JEL: Q01, Q20, Q40, Q51, Q54, C02

Correspondence address: Laurenc L. DeVita, Research Centre for System Risk Management, www.system-risk-research.org. E-mail: searcher@lastresearcher.com.
This article was developed in the framework of the research project "A Sustainable Future: Developing Knowledge For Educating Future Leaders In The Face Of Climate, Professional, And Social Challenges In A Complex World" funded by the Polish National Agency for Academic Exchange under the Strategic Partnerships programme (2024).

1. Introduction

The continued loss of ecosystems and the decline in services they provide is an existential threat to modern society. This paper describes the nature of the risk, possible efforts to respond to human caused environmental decline and climate change. It proposes there is a basin of possible outcomes which might allow society to continue, if risk is avoided. It considers the carbon dioxide molecule as the proper master variable for global degradation and proposes a simple methodology to identify and evaluate human activities, and their consequences for a sustainable society.

We can apply the methodologies and concepts discussed here at any scale or level of analysis, but Sustainable Development presumes a livable biosphere, which is what we "sustain." For that reason, a really sustainable human population would need to have a global approach, one which would manage population and resources for the biosphere.

That perspective gives us the acceptable definition of "sustainable development:" Sustainable Development means "living within the surplus of nature forever." A society of sustainable development presupposes a forever society.

The mission and methodologies of risk management. The risk manager is a "seer" of sorts; the purpose is to foretell calamity and avoid it. The process requires data, and a methodology to sort through complex data and find patterns of greater or lesser likelihood of occurrence. The product of the risk manager's work goes to policy makers.

The meaning of "risk" in a forever society. The Latin root of "to sustain" is "*sustinere*," which means to support, and to endure. A society which intends to live without destroying or depleting resources, that is, a "sustainable society," faces one singular risk: leaving the *basin of sustainability, that is, to exceed the surplus of nature.* That results in societal collapse and social dissolution, and all the human misery which attends the death of societies.

"Basin of Sustainability" refers to the group of possible outcomes which allow us to continue as a society. That is, when the consequences of our actions impact the environment in a way which does not diminish ecosystems. That perspective gives us the acceptable definition of "sustainable development:" *sustainability means "living*

within the surplus of nature forever." A society of sustainable development presupposes a forever society.

2. Where are we now?

If we want to "sustain" a functioning environment, we should know our starting point, that is, what it is we will "sustain." After all, our assumption is we maintain a working natural world, since it creates oxygen, purifies water and air, and gives us energy.

A study by Richardson et al. (2023), shows that we have exceeded six of nine planetary boundaries, some of which will require hundreds to thousands of years to regenerate, if ever.

The planet is heating much more rapidly than projections indicated (Mauritsen et al. (Mauritsen et al. 2025). People in the second half of this century will experience increasing climate instability due to carbon release into the atmosphere (Grant et al. 2025).

We are in the midst of a cascade of plant and animal extinctions (Cowie et al. 2022). Some say we are on trajectory for the Sixth Mass Extinction; in any case, we know that insects, which provide food for animals and which constantly clean the world by eating dead material, which aerate soil and pollinate crops, are in decline (Gebremariam 2024).

As we will see, we use tremendous resources to grow, process, transport and distribute food for humans. A significant question is beyond the scope of this paper but needs to be noted: is it ethical, or even possible, to harness an entire global biome for the perpetuation of a single species.

Our forever society has intensive remedial work to do to find a sustainable point between population, resource use, and a healthy environment.

3. Understanding the complex dynamics of the Forever Society

Physicist Albert Allen Bartlett coined the phrase "sustainable development" as an oxymoron; the terms in his view, were mutually exclusive (Cowie et al. 2022). Bartlett lectured frequently about "arithmetic, population and energy," apparently motivated by what he saw as the lack of a mathematical understanding of society which promoted the idea that development can be sustainable. His focus was, naturally, population since population is the one variable we can endlessly control.

"Arithmetic, population, and energy" are the focus of this discussion, though not just as Bartlett would have done. The primary perspective is that of Complex Bio-cultural Sociology, which proposes that society is a complex, self-organized system which arises from humans acting according to their propensities in a context.

The social system we wish to help continue is a *Complex Adaptive System.* Here, "complex" does not mean "complicated."

Something that is complicated can be explained in linear terms. Linear systems are predictable, because each part relates to the other part in a knowable way. So, a car engine is complicated, with up and down motions converted to circular motions and those motions are modified by gears, and taken to the drive wheels. We can follow the energy through it from start to finish easily, and make reliable predictions about their behavior. The system will never change, until it wears out or runs out of energy.

Complex adaptive systems are self-organized. They shift when energy flows change, and so are "adaptive." It means that there is energy available, and the energy flows in ways which do show a kind of equilibrium, meaning they have a consistency we can study, but not predict.

A quick and easy illustration would be this: we put two pieces of wood side by side on a conveyor belt; no matter how long the belt, the two keep their original relationship, side by side. We can easily predict the outcome: that is linear. Now, if we place those pieces side by side on a river, even a deep, slowly moving river, the two pieces will diverge. In a fast stream, they leave each other almost right away, but even a slow moving river will find them in different locations eventually. We cannot predict their relationships at the end of the river.

We consider Illya Prigogine, pioneer in identifying and understanding complex dynamic systems, who said that societies had "order through fluctuation" (Prigogine 1976; Jantsch 1976)." From our view it is only energy that exists, and energy which, following simple rules, organizes the entire system, but that is theory and we do not need to make it part of our methodology, except to remember that energy is everything.

4. The energy imperative

The systems we need to understand often have no functional mode which is not gathering and organizing energy, cascading it down scales of subsystems, because there is great competition for energy of all kinds. Wilhelm Ostwald described the primacy of energy in 1912 (Ostwald 1912). Alfred Lotka, a bio-mathematician, physical chemist, bio-statistician, and describer of the Lotka-Volterra predator-prey model proposed that the search for energy was the basis of evolution. Systems ecologists Howard T. Odum and Charles Hall used the term "Maximum Power Principle" (Hall, McWhirter 2023; Odum 1995)" when referring to natural complex systems and their need for continuous energy. Odum (1995: 311) explains: *"The maximum power principle can be stated: During self-organization, system designs develop and prevail that maximize power intake, energy transformation, and those uses that reinforce production and efficiency."*

Another conceptualization is the "Red Queen Hypothesis," proposed by Van Valen (1973), which uses Lewis Carroll's character from "Through the Looking Glass" wherein the Red Queen noted: "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!" (Carroll 1871). *The metaphor proposes that it takes a certain amount of energy to exist, and even more energy to grow or reproduce.* Further, we remind ourselves, in reference to "self organization," that the process never stops. The system constantly organizes itself, or it dissipates. A fire, for example, must constantly organize itself, regulate the flow of fuel and flow of air, and recover after perturbation. It does this by ceaselessly seeking more fuel and air.

A useful measure is needed which can allow us to determine how well the system is using energy, to offer a perspective which will function to reduce the intractability of complexity and allow linear manipulation of data, coupled with ceaseless gathering of data, so we can evaluate the risk of a project or system.

5. Energy return on energy investment

To make the discussion most accessible, we use the ratio "Energy Return on Energy Investment" and other concepts from Charles A.S. Hall (Hall, McWhirter 2023; Hall in: Tverberg 2018), and others, for conceptualizations of how complex systems of the sort we discuss function. Our system functions by turning natural resources into humans.

EROEI is a useful measure of efficiency, a cost-benefit analysis, and it further sharpens for us the imperative of all the systems we care about, from the individual human to the global society, to take part in energy flows.

"The surplus of nature" is the difference between what the systems of nature produce, and what they need to continue. Some years, in some instances, there is considerable surplus. In others, there may be a deficit. Surplus is important, which is why many animals find ways of storing surplus; a hole in the ground, a hole in a tree, fat around the belly, stocks and bonds.

A surplus of what? Energy in all its forms: food, warmth, movement, organization. Systems of the sort we discuss, humans and societies, are fully reliant on the capture and organization of energy.

It is about the efficiency that gives societies their form. It is a feature of such systems to seek all the energy possible, and to use it as efficiently as possible by channeling it through a cascade of subsystems across scales or levels of analysis. It is convenient to imagine the circulatory system going from the great vessels to the tiny capillaries, with information going both ways.

*Key to our analysis, we see a webbed and complex social structure, that is, the macro level, by which we mean the totality of humankind, the middle level, all their works and institutions, and the micro level, all their effort and offspring***.** Cities and

other "arteries," moving people and things, using a huge amount of energy, and a great deal of energy passes through them. Most energy is transformed, and sifted through several levels of analysis down, to the scale of the individual human. That is, to the things they buy, habits they keep, affiliations they have. The individual is the root tip of the system, and by reproducing, people reproduce the system.

Estimating the EROEI of the system requires data. It is relatively easy to capture data and calculate gross energy use at the macro level. However, a summation of those figures and the actual energy in the system are different. The micro level, people, store and use an astonishing amount of energy, and it is not easy to capture data on that level.

A quick analogy would be a football. Measure a football with a tape and get a nice clean measurement. Now, go back and measure closer to the surface, where the bumps and stitches are. The football grows. Deeper still, to the level of scratches and imperfections, and it grows again. The percentage of the whole which changes each time declines with each measurement, because of scale, encouraging us to simply use our first or perhaps second measurement. And, for gross calculations, we should always do that as a matter of thrift of operating energy costs. We have to accept that, over several iterations of calculations, our product becomes less and less accurately representational as a result of ignoring those subsequent inputs. As a result, we endlessly seek data to correlate our predictions.

6. Energy and humans over time

Considering energy and humankind, it is useful to think of the controlled use of fire, which began with Homo erectus, 600,000 years before *Homo sapiens sapiens*, about 300,000 years later. Fire, energy, did these things: it cooked food, which killed pathogens and internal parasites, and tenderized it, needing less energy to eat and digest; that allowed us to have smaller jaws, which might have facilitated speech; it kept predators away, reducing fatalities; it gave people something to sit around, and look at each other in the dark, and tell stories, which, eventually, the smaller jaws facilitated. On every level, through time, humankind has depended on culture that

followed, and was dependent on, energy.

This need to capture and organize energy to survive, and more to grow, applies to all systems on the planet. It applies to our forever society.

Complex societies need constant energy flows, since every modern nation desperately seeks growth in Gross Domestic Product (GDP) of at least 2%. Hence, the GDP is a generalized indicator of how much energy a social system has captured and organized. It is also a measure of how much of the environment we have converted to people and their possessions.

7. Logical assumptions about society

There are other natural "rules," or logical assumptions, we will have to be aware of, understand, and somehow compensate for. Here, briefly, are three.

First, *there is a direct connection between the complexity of a tool and the complexity of the society needed to produce it.* That is, it typically requires a society with long networks to different resources, and access to skilled people to make a complex tool. Complexity is strongly evidenced by the relative amount of energy it organizes. There is a direct relationship between energy and the form and structure of a society.

Hence, the windmill was probably in use by the 9th century (Lucas 2006), but the first windmill to generate electricity was a thousand years later, in 1883 Leonhardt 1884). Only 60 years later, in the 1930s and 40s, Jacobs wind generators were providing electricity to people in the rural parts of the United States[1]. Only 60 years after that, we see massive aluminum and fiberglass wind turbines with efficient blades and large generators. This seems to speak of advancing technology, and it does, but due societal, global change in complexity. So, for example, copper could be mined in one place, processed in another, stretched economically into wire in a third, and wound into a Jacobs somewhere else. This is important for us to remember for two reasons

[1] For example, my father, growing up on a remote ranch in Nevada in the 1930s, enjoyed a Jacobs wind powered generator for lights as a boy.

First, we cannot rely on complex technology to resolve our problems, because, as the EROEI of the technology drops below 1:1, it is no longer benefiting us. Artificial Intelligence, for example, is hugely carbon wasteful, and is not a technology that will survive a decline in global available energy. Second, if we constrain some projects, societal complexity will decline, as will the technology we can count on. For these reasons, we should find that lower technology solutions are potentially more resilient.

Population and population density predict a level of complexity. The second assumption is the effect on the complex global system of human population and population density; those are two different measures. We note that, in about 800 CE, when the first known windmill was used, the global population was probably about 3–5 hundred million people. In 1804, not long before the first wind powered electrical generator, it was one billion. In 1927, about when my father was born, it was two billion. In 800 CE, the largest city, with an estimated 125,000 people was Haojing China. In 1804 it was 1,100,000 people in Beijing, China. By the 1940s, it was 7,774,000, in New York City, US.

Population is important because, people "doing things" is the form of energy the complex system grows with, in addition to physical energy (like oil) and debt energy (like money) (DeVita 2023).

Population means people across the landscape. Humans have disproportionately long legs, and they walk great distances. They carry things with them, and when they meet other humans in the landscape, sometimes they fight, but most often, they exchange information, objects, and even things like rituals and beliefs. When humans walk the trails from place to place, networks are formed. Trade routes in particular, like roads, rivers, ports, and, now, rail and airports, increase social complexity. Those networks developed over the last, at least, three hundred thousand years, including Neanderthal networks in Europe and Asia before modern humans arrived (Ferentinos et al. 2012; Coco 2025).

The third rule is inviolable: weather always makes history (DeVita 2023). It drives migrations and wars and prosperity, and collapse (Peñuelas, Nogué 2023). That is easily proved: our global population remained very low for most of our 300,000 years; possibly as low as a few hundred thousand. Our population grew about 12–14,000 years ago, when the Holocene era began. The weather became mild and relatively

stable, and our population quickly grew to about 2,000,000. The weather stayed largely stable, and by 6,000 BCE, population was between 11,- and 14,000,000. A thousand years later, about 5,000 BCE, a good estimate would be between 18.- and 24,000,000. By the Common Era, 5,000 years later, it was likely about 255,000,000. Today, 2000 years later, it is (as of this writing) 8,229,644,467 (468, 469, adding about 2 people per second).[2]

Whatever caused such a rapid growth? Energy. Mild weather represents an advantage toward out-racing the Red Queen because it saves energy of all kinds. Some suggest the increase is due agriculture, which is a means of the system of culture, and that is true, but agriculture was made necessary by population growth (Cox et al. 2009), and population density, and possible by mild, stable weather.

And, in pursuit of food and there follows a cascade of technology over the next 11,000 years which culminates in the three curses of the 21st century which will plague us for several centuries, at least: climate change, plastic pollution, and nuclear material. We might add genetic modification, as well.

All of that was dependent on physical energy, first slaves, then beasts, then wind and falling water, and then coal and fossil fuels. Energy defines society, after Smil (2017).

8. How many people can Earth support

Here, we are regarding carrying capacity. It should be clear that "sustainable development" is that which stays below the carrying capacity of the environment. Living on the surplus of nature means living within carrying capacity, of the physical planet, and of our manipulation of it. There are many ways to consider the carrying capacity of the human population (Cohen 1996).

8.1. Critical resources as limits

Carrying capacity is clarified in our concept by considering Sprengel-Liebig's law of the minimum, which states that a population is limited by the relative scarcity of a

[2] https://www.worldometers.info/world-population/ [18.06.2025].

single resource. The idea is simple enough to state, but becomes more nuanced in practice, because species and individuals act to overcome such limitations (humans doing things is energy). Further, some critics might deny that the law applies clearly when communities of species are considered (Danger et al. 2008), which might seem to soften the usefulness of the idea to us.

Another way to frame the concept is by considering the positions of Thomas Robert Malthus (1798) and Ester Boserup (1985). Simply, Malthus noted that a single condition, the availability of food, can determine population and population growth rates; Boserup maintained that humans are resourceful and can manipulate the environment (we would say "use culture") to increase food or harvest and use it more efficiently. Boserup, however, does not negate Malthus, because, ultimately, there are finite resources on a finite world; technology can expand only so much before the limits of EROEI overcome successive attempts, and the diminishing return halts development. Attempts to overcome the shortage usually include finding alternatives, which are typically less efficient; reducing usage, which dampen energy flows; and violate the prime directive, which is to "be sustainable."

We will use the idea of a law of limits; the concept is still very useful (Hiddink, Kaiser 2005) to us. In this discussion, the "law of minimum" refers to the inevitability of depletion of critical finite resources, and the added energy costs of alternatives, and the constraint of living within the surplus of nature. This limit will allow us to evaluate our dependency on each resource. At what point does a scarcity of a resource constitute a risk to our sustainable society? Using data available, we must determine the social system's dependence on it; the availability and increased input costs of alternatives; and, the changes and increased costs which might appear in related resources. We make subjective decisions, because an educated guess is literally the best we can do, and quantify that as the value we apply to it to modify energy investment in its use. This is a process we repeat for each resource input, modifying energy invested for each to reflect the risk.

8.2. Irreparable consequences of driving the climate

All that human energy seeking has brought us to a hot, increasingly unstable climate. The climate is leaving that mild, stable period of the Holocene and moving

into the Anthropocene (Eugene F. Stoermer appears to have coined the phrase in the early 1980s; Crutzer, Stoermer 2016), the time of human caused climate change and global environmental collapse,. Beginning in the middle 1700s,[3] carbon pollution increased rapidly. The amount of energy trapped in the form of heat by our atmosphere has doubled in just 20 years (Mauritsen et al. 2025). Our Society of Forever will have to account for the loss of energy that will entail, in everything from transportation and maintenance of infrastructure, to growing (Hultgren et al. 2025), transporting, processing and distributing food, energy generation and distribution, and managing migrating populations. We will, in our calculations, account for the instability of weather as a separate variable modifying energy invested.

8.3. Tracking climate change from the source

One efficient way to do that is to track changes in GHG emissions in CO_2 equivalent. It is a good indicator of the degree of instability heat is bringing to our climate, and we will apply the percentage of change in emissions as a percentage of carbon invested (Filonchyk et al. 2024).

We might suppose that the increased costs of climate change would appear already, as energy costs increase. So, for example, if a flood or drought destroys tens of thousands of acres of crops, that would appear in data regarding harvest rates, and again as increased costs to consumers as scarcity increases relative demand. That does not illuminate, for our purposes of forecasting, how weather unpredictability might increase all other costs, including health and social stability. *Climate change has to modify investment even though we are applying it twice, once as an energy use modifier in the present, and once as a projected feature of the future. We do this later by considering the trend of the data for a known period of time, to establish a crude estimate.* We know we will be wrong, and so we ceaselessly gather data and modify investment costs as indicated. The rate of change in carbon emissions can provide a percentage which we apply to the overall investment cost.

Population, and population density, are central to our discussion, because humans are the medium of the complex social system. Humans engage in inherent

[3] We could push the date back ten thousand years: ice cores apparently demonstrate increasing CO_2 from Neolithic farmers.

behaviors. It is humans which consume resources to make more humans, and their number, with unrestrained resources, increases exponentially.

But, the natural laws on population are very complex. For example, there is a minimum population size below which communities and societies and even species cannot survive (a "tipping point," below). We briefly discussed the relationship between population density and social and technological complexity.

Not just population, but demographics require our consideration. For example, a population with more people over 50yo than people 15–35yo is not going to increase rapidly, as is obvious.

But, as constraints on resources increase, older people are more likely to die, leaving a young population able to reproduce, with relatively more resources. If, as risk managers, we have the funding and actuarial resources, the demographic shape of the population would be included in our assessments. It might be concluded that some demographic patterns would increase, or decrease resources across time.

8.4. Uneven resource use and inequality

Population describes one variable on resource use, but not all humans use resources equally. Economic inequality is generally present in some form in most complex societies. Some explorations of resource depletion create general categories of resource use, from the very poor to the ultrawealthy (Motesharrei et al. 2014). The rationale is simple: people who use more resources will exhaust the supply more quickly than people who live simpler lives. That is, there are a finite number of resources; we can spread them thickly over a few, or very finely over many. What is the desire of the policy makers, that there be a better life for a few, or a constrained life for many. In our discussion, we are not policy makers, and so we will simply consolidate data from all social classes and stages of development for our work, and allow policy makers to determine how to deal with the problem of social inequality.

In our consideration, where we intend to develop and persist in a sustainable manner, the closer we allow population to rise near the fluctuating carrying capacity (the surplus of nature changes according to unpredictable elements, like weather and disease) the more certain we are to have social upheaval or to violate our prime directive to be sustainable.

The pressure from policy makers to figure the data to allow development might be intense. There will be social demands which might tempt us to figure EROEI not from this year's data, but from a hoped-for surplus, as opposed to a verified surplus. That is gambling and increases the likelihood that our predictions are wrong, we misjudge the risk, to our global detriment. We would "owe" to the surplus of nature.

If we violate our prime directive and take more than the surplus of nature, we create a kind of "*sustainability debt*." That is, we increase the time nature requires to return to a healthy and productive stage where it can, again, create a surplus. If we persist in our use of that resource, it may drop below a level where regeneration is possible. These are "tipping points," below which recovery is impossible.

All resources, and in particular, living and renewable resources, have "tipping points."

It is very dangerous to run a sustainability debt, because we can damage irreparably those natural resources we rely on to live. Further, we seek two separate goals in our effort, first to preserve the surplus of nature, and second to produce resources for human consumption, to create more humans. Those two goals do not appear to often have a serendipitous "sweet spot" where both are easily met (McClelland et al. 2025).

The inevitable cost of unintended consequences, or "exteriorize costs." Those costs to the environment which are often invisible in economic considerations, are of prime concern to us. For each determination of energy return on energy investment, we must have a value for our sustainability debt, also known as "environmentally burdened exteriorized[4] costs," or "externalities" (probably Marshall 1920). These are energy costs of a project or societal system born by the environment. Those costs include things like: CO_2 emission; road building (meaning oil, rubber and other pollutants; disruption of animal and human migration routes); disruption or pollution of aquatic and marine waters; over-harvest; disruption of human systems which were living sustainably. There are many others, and determining the true cost

[4] The concept of "exteriorized" costs and benefits typically refer to "unintended consequences" or "secondary effects." In our work, the term presents difficulties, since there are uncontrolled or unaccounted outcomes. Some authors try to consider "positive and negative" externalized effects, but it becomes problematic because, in an energy hungry universe there is a zero sum outcome. Here we discuss specifically unintended outcomes which increase our sustainability debt.

of them is difficult, but necessary, because when the exteriorized energy costs are considered, many projects and resource uses are revealed as creating a sustainability debt, and so are unsustainable.

9. Approaches to exteriorized costs

At this writing there are good examples of attempts to capture costs exteriorized to the environment, including the United Nations Environment Programme Nature Risk Profile: A methodology for profiling nature related dependencies and impacts (UNEP 2023). The methodology is described like this:

The methodology developed here is aimed at using input data with different levels of spatial detail, structured around two core 'tiers'. The most accurate and spatially precise profiles of nature-related risk exposure will be based on geolocated asset level data ('Tier 2' e.g., buffered point, polygon or line data), in line with the focus of the TNFD on understanding location-specific nature-related risks. Where asset level data is not readily available, estimates of metrics at a broader sectoral and spatial resolution can be used to estimate potential risk exposure ('Tier 1'). Methods to estimate likely locations of sector activities within countries can be used to refine sectoral approaches used in Tier 1 assessments. For example, layers representing the spatial breakdown of GDP production within countries can be used to weight average impacts and spatial risk factors

Though this is not precisely the methodology needed for our task, it outlines a logical approach, and indicates or implies the limitations of data.

Even so, we proceed to logically organize our resources into categories to context data and allow us to apply values, and so manipulate. (See, for example, Gerten et al. 2025). We might divide the Earth into watersheds, or climactic zones, or latitudes, or nations.

We could describe and monitor "planetary boundaries" which divide resources into broad logical categories (Rockström 2009; Steffen et al. 2015).

Our unique approach will dictate the methodology. Our work is to consider each resource, first, its current state as compared to a historical healthy state, and next, our

relative dependence on that resource, and next, the relationship between that resource and other direct and indirect resources, and their state relative to historical healthy state, and our dependency on it, particularly if the primary resource were exhausted. S&P Global Sustainable1 report for 2024 uses the idea of “impact pathways” (S&P 2024: 72). We will simply follow and record energy flows between inputs.

That is only a primary and secondary analysis, whereas we might, if energy were not a consideration, expand to subsequent effects. But, energy is our primary consideration and the complexity of the problem increases exponentially as we include more pathways or variables, as does the energy to pursue them.

Even so, in the construction of our networks of inputs, a skein of relationships will be evident, demonstrating down-stream exteriorized costs, and revealing patterns of consequences to our resource.

Monitoring risk for our society, we always track the state of our resources and know the surplus limits of each we can live within, (to the degree that can be known in advance). We already gather reliable data demonstrating the health and continued productivity of the natural world from which our resources spring (the entire biome generates our oxygen, for example).

Exteriorized costs can be accounted for by modifying energy invested in our calculations. In our calculations, we will always modify “energy invested” with a value of exteriorized costs. That will go part way to reducing the ease with which a sustainability debt can accrue. It will also facilitate policy to avoid tipping points.

However, there are significant, probably insurmountable, problems with determining actual energy investment and return. If the world were arranged in linear grids, then following energy through the system would be no more difficult than counting chickens. The grid may be complicated, but it can be completed with a step by step linear formula. It tracks variables in a usable format. We would then see the investment and the return. A simple example might look like this:

The value of the first energy input, plus the value of the second energy input, and so on, to be summed. That is the invested energy.

The value of the first energy return, plus the value of the second energy return, and so on to be summed to present a divisor of the first number, giving us our energy efficiency, or EROEI.

$\frac{\sum_i^n v_i \cdot R_i}{\sum_j^m w_j \cdot I_j}$where v_i are the weights on the returns, R_i, and w_j are the weights on the investments I_j.

But, what we want to know happens in different scales of time, with many back currents of energy, and so variables which change relative to each other over time and "distance." "Distance" here meaning not simply a measure of space, like the length of a road, but by accessibility, and "accessibility" is a measure of energy needed. Now, instead of imagining a grid, we must imagine energy endlessly flowing, but never flowing precisely the same from instant to instant. Now we see that the world is rich with "unintended consequences," which both increase and decrease the ratio of return and investment. We also see that energy return represents an energy loss elsewhere in the environmental system. All energy in the system is sought after; when someone gains energy, someone loses.

We cannot know everything we need to know regarding energy magnitude across cycles of time, distance, and scale. It would require more energy to completely do so than our effort can afford. It is a known limitation we accommodate.

10. Determining which values best suggest the basin of sustainability

Consider the likely impact of the project or social system we analyze. The difference between the healthy state and the current state is quantified. By that, we mean to determine the surplus of that resource from earliest data and the most recent surplus, and determine rate of change.

A simple annual surplus does not tell us much; we need to see how well that resource has done historically, how it is doing recently, and imply how it might do generally for a period of years. We weight our calculations with the percentage of change which is applied as a percentage to investment energy costs. We can suppose that if the resource is generating a good surplus, that our exteriorized costs are being absorbed under our primary goal.

If it is not, then we assign a value to it relative to the percentage of the shortfall of surplus, modified by the resource's limit to our sustainable survival, as a carbon value. So, if a freshwater resource is diminished, we determine the rate of decline, and

that percentage is added to the investment costs. We determine the value of the water lost (as we do below to determine .02 kg per liter for recycled water) and multiply that to the total volume in liters. We also apply an additional carbon value per liter to the water, if the fresh water is lost and not recycled, raising the value to .04 kg per liter.

10.1. Sudden changes in resource systems, including the climate

That assessment needs to be modified further still by considering the fragility of the resource. The term "tipping point" (Lenton et al. 2023) refers to sometimes sudden, often permanent changes in the system due to passing minimums, or limits. For those unfamiliar with the concept, think of that last straw that caused the camel to finally suddenly collapse. Note that "sudden" is a relative term, and large systems have momentum, but if the tipping point has been passed, they are losing cohesion.

Species, natural resources, and human societies have tipping points, as does the climate system.

Because the systems are complex, there is no way to know precisely what circumstances will cause sudden change. Or, the consequence.

Our forever society has many tipping points; if we exceed our resources, they will become evident. All represent dire consequences, and so justify the energy to gather data and determine the resilience of "limit" resources; using the law of limits, we can make meaningful assessments, which we constantly compare to real world data.

We have to be parsimonious and efficient with our effort, and so have to have definitions and criteria we can use to derive meaningful information. *Carbon pollution is our primary concern.* It figures in nearly every other variable we analyze, from climate change, to sea level rise, to ocean acidity, development and expansion, population, nanoplastic pollution, food production.

10.2. Assigning a useful unit of energy

To facilitate our effort, we need a unit of energy, in the sense of "investment." We might use a currency for convenience, but those are an arbitrary, and changeable unit. The "watt" would be a more accurate unit, but it applies easily only to physical energy, and not the activities of humans or the power of debt in development.

The best measure is the carbon dioxide molecule. Carbon dioxide is the primary

factor for risk, as it has "multiple effects on the biosphere" including negative effects from long term exposure (Bardi et al. 2025). Using the value of the CO_2 molecule allows us to link "development" to its true costs. We have data available from exterior sources on the carbon use of most things we care to measure. We can arbitrarily assign "one carbon unit" to the carbon dioxide emissions of one person living in one day, one kilogram a day.[5]

This also gives us a value for the primary driver of the system, the human. What literally powers the system is humans doing things, consuming, reproducing physically and reproducing the context of the system.

10.3. Accounting for humans

It is useful to be objective about humans, since they are a variable we must account for. We know that humans consume resources and through cultural processes, release not only carbon dioxide, but also lead (it is possible to track Roman silver production by reading lead deposits in ice; McConnell et al. 2018) radioactivity, and several toxic, long lasting solvents and plastics into the environment. It might seem most convenient to reduce risk by eliminating the human variable, but, then, the forever society would be gone.

As a result, humans are a neutral value to our ratio, except for their number. Population is multiplied by 8 kg (presumed to be the ideal minimum carbon emissions of one person and necessary provisions[6]). If the population, however large it was, consumed only within the surplus of nature, our prime directive would be met. What emissions would those be? We already know, 1 kg CO_2 per day, what it takes to maintain life. At that rate, we are producing the CO_2 a mammal our size would contribute to the environment, including some nitrogen.

However, a person who could live within a small carbon budget, someone who used no fossil fuels for food and shelter, in reality and in the manipulation of the data,

[5] This figure is an estimate based on normal food intake and activity, but the methodology was not specified. We use it because it is the most reasonable estimate located. If more precise information becomes available, we will update our constant.

[6] We derived this number from estimates for individual CO_2 use in the nations using the least carbon. A poor Indian farmer, for example, might have an emission of less than 1, but few people live in a warm climate where food plants grow readily. A daily emission rate of 8 kg allow a sustainable population, but not excessive population.

carries part of the burden for concrete and steel mills and airliners that she will never use. In the data, most commonly we see the carbon estimate for the nation, divided by population, divided by 365 for a daily carbon cost. It is there that the farmer or herdsman collects an unfair share of the debt. And, in the real world, climate change and water pollution and land lost to dams and development or agribusiness farming is a tangible exteriorized cost to the poor. Whereas the wealthy have enough surplus energy to move and avoid the worst of climate change, the poor are often tied to their land through inheritance and family, or even by bond. Climate change migration and displacement is increasing as climate change increases (Opitz Stapleton et al. 2017), However, we recall that the level of technology requires a level of social complexity to produce it.

Eight kilograms per person per day would appear to be the least CO_2 a person can emit and live a pleasant life, and perpetuate complex society. In harsh environments, twice that would not be enough. It is a policy decision whether more carbon should be allowed for places that are too hot or too cold to live without large carbon expenditures. The number is on the high side of what should be sustainable, unless demand, that is, population, declines. The US, by some estimates, consumes 35 kg per person per day. On the other hand, a person from Burundi uses 1.7 per day (EDGAR 2025). Eight kg a day is about the per capita carbon use of Mexico.

10.4. Greatest threat to our Forever Society: carbon

Essentially, by using carbon to determine the energy return on investment, we address the greatest threat to our society. Carbon dioxide is emitted in ways which release other greenhouse gases, including nitrous oxide and methane; reducing fossil fuel use will result in a decline of all greenhouse gases, which constitute a grave risk to our society. Nitrous oxide, which is 300 times more efficient as a greenhouse gas than carbon dioxide, is produced by agriculture and other human activities. Methane, CH_4, degrades to carbon dioxide, after 20 years, and can be counted that way, but we have unaccounted greenhouse gas during that time, and must neglect N_2O because there just is not sufficient data. Sometimes estimates are made for “total greenhouse gas in CO_2 equivalent;” we will use those with annotation when appropriate.

Carbon dioxide is still our best variable on which to assess systems and projects,

but, we are justified in additional carbon and other GHG cost which we know is there, but for which we cannot obtain objective data.

To complicate the problem, there is currently "global dimming" because of particulate matter, mostly from burning carbon or activities which likewise increase particle release. When carbon release declines, the clearing skies will add more heat to the system. There are technological remedies, like high altitude aerosol dispersal, but they are temporary solutions, and include serious risk to the climate. When directed to consider the risk of those practices, we will use our methodology.

10.5. When the data is in currency; a means of conversion

When considering the data available, we have a translation problem when our best data is in currency. Currencies fluctuate in value and complicate analysis.

A practical solution is to use the cost of one liter of diesel fuel, which is 2.68 kg of carbon dioxide. Diesel fuel is involved with agriculture, transportation, and industry, and the price is reflected in the cost of all of those products. Eventually, as fossil fuels decline, we will select a new basis for converting currency value to carbon dioxide.

To frame our modifications of input costs, we need reliable data, or information produced from data. In terms of our energy investment, more than half should be expended on gathering, organizing and evaluating data. Risk management is prediction; it has to be endlessly correlated to real world data. Is there a change in the number of trees, globally? Does it match our threshold for sustainability? Is there a surplus in some areas, but a decline in others? What is the ratio? Are forests moving upward in elevation and latitude? What was our prediction, and if the results were not as expected, what variables explain the difference?

We need to know these values:

1. the total unmodified, or, naive, amount of energy intended for the investment
2. the inventory of primary and secondary resource inputs
3. for each input:

*The value of the resource as a limit; that is, how critical the resource is. The more critical the resource is, the greater the value.

*The resilience, or estimated distance from a tipping point,

*Likely exteriorized cost to the resource, determined from historical data,
*Relative impacts on related inputs
*Carbon dioxide emissions of elements of the project, to primary and secondary inputs. This would include the carbon used in three stages: construction; operation, and deconstruction.
4. the climate change impact, which is determined by the susceptibility of the project of analysis to unstable weather using a likelihood from historical data following a trend of rate instability[7].
5. the atmospheric carbon dioxide factor, a value which increases exponentially from the rate of upward change as the carbon and GHG gas emissions increases over the preceding ten years. Data for that period is not always available, so we use the trend in the data over the years we do have. When the atmospheric carbon begins to decline, an estimate of remaining carbon levels as compared to the target of 1750 CE, and a value is added which represents the project's or system's portion of the remaining excess. When the proportion of carbon dioxide returns to base proportions, the factor becomes 1[8]. The most recent numbers available at this time are unavailable at this writing, but for the last 14 years available, 2010 to 2024, taking record highs as a primary indicator, are 394.02 to 424.87 ppm[9], an increase of roughly 30.85 ppm. We can use that 14 year period and determine the percentage of increase. The added investment cost is that percentage of increase as the basis applied to the total carbon investment.

It is immediately apparent that we are modifying the input for carbon in at least three terms: the carbon dioxide emissions of the elements when they are made and transported; if the emissions are high enough, they enter as an exteriorized cost; and again as accumulated atmospheric carbon dioxide. This is for a simple reason: if we continue emissions as we have, we have a fair likelihood of changing the climate beyond what we can survive, and certainly beyond what complex society can survive.

In the instance of each energy resource input, we have to consider the proximal

[7] We recognize that weather events, like earthquakes and other events, in terms of magnitude, occur aperiodically. It is the trend over time we follow.
[8] The proportion of CO_2 from 1750 might not be sustainable. It seems neolithic farmers were already adding CO_2 and changing the climate. See ScienceDaily (2018).
[9] Record peaks using archived NASA data, https://www.co2.earth/co2-records [07.10.2025]. At this writing, the Trump government has discontinued updates.

impact, for example, the percentage of the functional trees in a wood effected, and the tipping point of that wood, and the extended impact on trees in the watershed, regionally, and globally, with implications across time. An example of implications across time would use the deforestation rate historically, and currently, and encroachments as a percentage, and how climate change is impacting reforestation. We seek only negative impacts, because positive impacts will be captured in surplus figures, and present no risk. If there is still a decline in the forest, we increase our investment modifiers. (Our scope is narrow and deep; there are other providers who track improvements and determine best practices.)

11. Positive elements of projects, for example, those which save carbon or restore an ecosystem

What about a project which saves net carbon, or otherwise restores or encourages environmental inputs? This reduces risk. Our mathematics remain the same; the value, in carbon units, is determined, but the investment is reduced, removing an indicated carbon cost value from the total carbon investment.

But, externalized costs hide in unintended consequences. For example, a small nuclear plant is planned. Using modern systems, it emits less radioactivity than a coal powered plant, cannot "melt down," and needs relatively little carbon to construct. It would seem to have a considerable return on a small investment. However, what are the downstream or exteriorized costs? Does it replace a similar output carbon fired power plant, or will it drive consumption under "Jevon's Paradox"? The paradox is that the more energy available, the more uses will be found for it (Alcott 2008), and it will drive consumption of resources until the limit of energy is achieved. See "maximum power principle" above.

We cannot foresee all the unintended consequences, and so we have little choice but to either "determine," which means, "guess" what those outcomes would be, or preferred, do the work and determine it has a good return on investment, but caution policy makers that subsequent projects which spring from it might not have acceptable EROEI outcomes, and the plant might be built, but not fully utilized. It might mean a

greater demand for copper, which is carbon intensive to mine and smelt, for example.

11.1. Stages of emissions

When analyzing a plan or currently functioning system, we recognize three probable levels of carbon use to determine. First, is the cost of set up, that is, construction, land use and so on; second, the cost of operation; and finally, the cost of replacement or demolition at the end of the projected life. If the system uses on-going resources, then the cost of maintenance and operation, unless it uses energy as part of its operation, for example, as steel plant or a desalinization plant for water (Heihsel 2019) will be greater than construction costs. In a well-designed system, the initial period should see the most carbon use, and demolition the next most. In operation, the system should not exceed 8 kg carbon emissions per person served. If a system provides a service at more than that limit per person it is immediately not sustainable. If policy makers determine that carbon loss could be saved elsewhere to provide a critical service, we can analyze their proposal, and make evaluations, or, they might ignore us entirely, which is not our problem.

But, what of systems that provide inputs to the social system which are critical? There is no scale of nature which can be ignored, even down to the microbe level (Junker, Farwig 2025).

Determining the value of the resource as a limit; what would be the consequence of running out of the resource. What are the tipping points of the resource?

11.2. Fresh water

Fresh water is critical to human life, and to the production and processing of food, and many manufacturing processes. One source estimates annual global water use at 60,000,000,000 cubic meters (Shahzad et al. 2017). Only a small amount of fresh water is potable; most has to be cleaned and treated. Urban areas represent an efficient way to house humans, because of the expense of distance. Distance creates carbon; cities and apartment blocks reduce the distance for each person for water and waste, and electrical power. Cities recycle water.

But, urban areas still consume large quantities of water and produce large quantities of waste. In many municipalities, the sewer cost is billed at the same rate

as water, because it is assumed that all water that goes in comes out as waste. We will use that rationale, and for domestic and other uses directly pertaining to humans, we will charge twice for fresh water, that is, unless a compensation plan is provided.

Cleaning waste water to produce new fresh water is carbon expensive; in the past, nature purified our water for free. The water in cities comes from somewhere, usually several sources. Surface water is useful, but has become increasingly polluted, and is a necessary part of a functioning ecosystem. There are many historical exteriorized costs to fresh water use; all exteriorized costs have to be considered. Cleaning and distributing surface water is carbon expensive. Subsurface water is diminishing and being polluted with microplastics, "forever chemicals" such as the 12,000 types of PFAS, "per-and polyflourinated alkyl substances" (Smalling et al. 2023). Pumping freshwater has caused subsidence in some cities and land areas (Ohenhen et al. 2025). Pumping subsurface water is related to sea level rise (Rodell et al. 2024). The rapid decline in fresh water is changing the balance of fresh to sea water (Chandanpurkar et al. 2025). Terrestrial water storage has been on the decline since 2002, and continents experience increase in the amount of dry land. One person in four in the world lack ready access to safe potable water (UN 2024).

Desalinization is very energy intensive, as previously noted. It includes "conventional reverse osmosis (RO), multi-stage flash (MSF), multi-effect distillation (MED), electrodialysis (ED), and mechanical vapor compression (MVC), and the emerging membrane distillation (MD) and humidification-dehumidification (HDH)" (Wang et al. 2024).

Finally, CO_2 is replacing oxygen in marine and fresh water sources (Rose et al. 2024), which is having a negative outcome on life in the seas, which includes other negative effects of CO_2 increases, like acidification of the seas (Bardi et al. 2025).

We can determine that freshwater is a primary resource which is in decline (Zhang 2024). If the demand for fresh water grows, we will see increasing energy dedicated to it, and increased carbon usage (Shahzad et al. 2017). If it is solar, wind, or hydro generated, a portion of the carbon of production, installation and maintenance is added.

We can only make a rough estimation of the tipping points on any resource, and cannot be certain until we exceed the limit of this resource. Further, in seeking a value

for fresh water, we see that the only alternative is to burn carbon or other energy sources to clean or desalinize water, and emitting carbon worsens pollution of the atmosphere, and changes climate, and further destroys the seas, and so compounds the crisis of fresh water.

Because freshwater is critical to development, as well, it is possible that mitigation schemes might become popular. How do we rate those? In the same manner, however, fresh water is a finite resource, and taking it from a source deprives legitimate water use for other inputs, including nature. If carbon is used (for solar, wind, and hydro, we figure the carbon cost of building and maintaining, and secondary consequences of siting), that exponentially increases the true investment costs.

By what value? A limit issue which is already in decline should have a significant added cost; that is, for the quantity of fresh water used, there is a modification to the value of carbon necessary to clean that amount of water. However, in addition to the cost of carbon, the process of cleaning or desalinizing fresh water creates hyper-concentrated salt or other pollutants (Panagopoulos, Haralambous 2020). That impact would require its own analysis, and proposed mitigation would also require full analysis. The carbon used to clean the water would be included in its own metric. It is possible that more efficient processes might emerge; when they do, the analysis will modify investment cost. The proposed project or system might save carbon in some other aspect, or might save fresh water ultimately, and that reduces the increased cost of investment. Until then, we must determine a carbon value for fresh water, which is difficult to accomplish (Cornejo et al. 2014). Data indicates reverse osmosis as the lowest carbon footprint in operation, but evidence of the carbon footprint for its manufacture and the disposal of badly polluted water resulting were not clearly available. *Our final value: 0.02 kg carbon per liter of water for water that is reused, and .04 kg for water which is lost.* We have little certainty that figure captures all the exteriorized costs.

11.3. Sea water

The oceans are suffering from human caused perturbations of the marine systems. Carbon dioxide pollution and agricultural practices have heated the oceans and caused them to become acidic (Doney et al. 2020). It has shifted the ocean currents that partly

stabilize weather (Nat. Clim. Chang. 2024). Carbon is responsible for the plastic which pollutes the land (MacLeod 2021) and permeates the seas, the most dangerous are microplastics which compete with nutrition for many kinds of animals, including whales. As noted, above, sea water is being diluted, and oxygen is declining. Desalinization plants release concentrated brine and other pollutants, as noted above. The small but very numerous phytoplankton, the base of most animal life in the sea, are in decline in the warming oceans (Ribalet et al. 2025). Changes in ocean currents will perhaps prevent the upwelling of nutrient rich water, as has recently happened near Panama (Guzmán Bloise et al. 2025).

Plastic, and in particular, microplastics (Alfaro-Núñez et al. 2021), are a serious threat to life on land, as well as the sea. Described as less than 5 mm, this class contains plastics which are more dense than seawater, and precipitate to the sea floor, and others which are lighter, and so accumulate on the surface. They enter the ocean from the land, and the air, and are the result of mechanical abrasion, resulting from tires, laundry streams, industrial production and overboard dumping (Thompson et al. 2024). Microplastic pollution is practically irreversible (MacLeod et al. 2021).

How do we value the seas? We cannot afford to have anything which degrades the oceans. No agricultural run-off, which poisons fresh and sea water with nitrogen, which causes, among other problems, plant growth and death which causes hypoxic zones. No industrial outflow; no vessel dumping refuse or human waste, no discharge from cities. Even outflow from desalinization and osmotic filter water recovery plants. *We propose a value of 0.1 kg carbon* per liter of sea water damaged should be applied to any project or system which pollutes the sea. Since there is no input sufficiently low in carbon, that is, there is no way to remove the pollution from the seas, only an extremely risk reducing, in our primary sense, project will have a sufficient return on investment.

11.4. Arable land: forests, wetlands, prairies, deltas and other natural ecosystems

No land was “arable” prior to settlement farming. Forager people who most often wander the land in a seasonal way seeking known and opportunistic resources, have, for a long time, practiced horticulture, preferring and even planting some plants, and discouraging others. Some burned grass to drive out game and ensure a strong crop

the next year. Early farmers, and farmers today, practice “slash and burn” agriculture, which destroys and burns native vegetation, to release stored nitrogen, potassium and phosphorous, as well as other trace minerals, for their own crops. Slash and burn farmers also wandered in search of resources, not just because they also hunted and gathered when possible, but because they would exhaust the soil in one place, and move a short way, or a long way, depending on circumstances, to slash and burn again. Hence, there is no fully natural “arable land.” Humans have drained swamps and wetlands, clear cut forests, burned and plowed prairies, and colonized watersheds to convert them to “arable land.” Currently, in most places of industrial agriculture, soil is simply a substrate to which fertilizers and amendments are added. Agriculture, at this writing, uses 150 lbs of amendments, on average, per acre of land, per year. Some of that is released as dinitrogen monoxide, N_2O, a greenhouse gas. Some fertilizers run off the land to pollute water sources. Agricultural production of beef and pork typically results in feedlot run off, sometimes polluting downstream fresh water, leading to weed choked waterways. The carbon cost of creating fertilizers, not just nitrogen but potassium and phosphate, generate several tons of carbon dioxide for every ton of fertilizer (Tian et al. 2020). We are justified to add a carbon cost of 2,000 kg per 1,000 kg of fertilizer.

The UN Land Report estimates “Food systems are responsible for 80% of deforestation, 29% of greenhouse gas emissions and are the single largest cause of biodiversity loss on land” (Chandrasekhar et al. 2022). Hence, though arable land is a critical resource and we will value it as such, we recognize that all arable land represents the degradation of a functioning natural system, and that arable land, in production, releases N_2O and CO_2.

Even so, we will analyze the carbon inputs on arable land. Since the energy return considers population times 8 kg for an ideal use of carbon per person per day, the return should cover this high carbon cost investment.

The loss of arable (Gauri 2019) land is through development, erosion, desertification and salt burn from misuse of fertilizers, and toxicity from repeated applications of pesticides (Prăvălie et al. 2021). Erosion, in particular, creates significant risk (Quinton, Fiener 2023). In many cases, reclaiming much of that land is impossible. Due human activity, the continents are drying, which effects arable land

as well as other land forms, and even sea level rise (Chandanpurkar et al. 2025).

Further, some types of agriculture are energy intensive, considering Haber-Bosch nitrogen and other chemical amendments, and pesticides and their application. Not all forms of farming produce the same EROEI (Rasul et al. 2024).

So, projects which maintain arable land do not have, for our purposes, an initial input cost, because they are essential, and do not decrease natural systems. If the maintenance plan conserves water and limits chemical amendments and pesticides, it earns a credit, that is, a reduced investment cost, which will have to be determine qualitatively for each unique project.

In specific instances, we can make an EROEI investment cost; in general, we have to assign a value which considers the nutritional value of the food crop, and the number of humans it would support, and the carbon cost of growing it. An acre of functional farmland growing food for humans would be considered to have a positive EROEI, if it produces more food than it uses carbon. Processing and transportation use a great deal of carbon, and have to be accounted for. Growing food for animals for human food has a lower return, especially if the fodder was transported and processed before being used for livestock.

However, not all land is suitable for growing crops, but it produces plants humans animals can eat, and its use can be strictly managed. The management plan to graze animals on natural systems would be analyzed in the same way as any project.

An acre of arable land, including grazing lands, have the same carbon loss value as an acre of woodland. Likewise, restoring an eroded, exhausted or otherwise barren land to arable land has a carbon cost reduction of that same value.

A project that creates arable land from forests, wetlands, prairies, and other functioning natural systems will find dramatically increased investment costs, since it is violating the prime directive and reducing the surplus of nature.

Externalized costs on each land form would need to be estimated using the normal methodology; determine their value to the continuation of society, and their tipping points, their fragility and resilience.

An example would be woodlands. Forests and other accumulations of trees and large bushes are complex ecological systems that provide many ecosystem services to the sustainable society (Brockerhoff et al. 2017). They slow water and prevent

erosion; they accumulate organic value in the soil; they help prevent flooding; they balance CO_2 (Besnard 2025) and release oxygen (they also release greenhouse gases, as part of the recycling of CO_2, nitrogen, and loam); they provide an environmental context for uncountable numbers of plants and animals, and humans (Shrestha et al. 2025). An analysis of human population as compared to deforestation predicts global social collapse if we continue at the current rate (Bologna, Aquino 2020).

Forested land is under stress from deforestation (Mgelwa et al. 2025), mining and development, and climate change, which increases heat stress, drives the treeline up in altitude, and changes precipitation patterns, desertification. Deforestation also impacts climate change (Lawrence et al. 2022). Even the mighty Amazon Basin could pass a tipping point due deforestation and a drying climate (Hajdu et al. 2025).

Trees, and vegetation, absorb light and heat and, seasonally, cool more than they heat (Li et al. 2025), meaning they are an important resource for that reason.

Further, a crop of same age, same species trees on a tree farm is not a forest (Van Holt et al. 2016). A forest is a complex system which relies on different aged, different species trees and shrubs.

Likewise with all natural land form systems. Wetlands allow for biodiversity; and clean water; prairies and all natural systems encourage biodiversity, the loss of which indicates the Sixth Mass Extinction and could lead to our collapse (Strona, Bradshaw 2018). The fragility and resilience of each needs to appear in our input as exteriorized costs to a critical resource.

How do we price ecosystems; what is the carbon and biodiversity cost to destroying an acre of natural land, when arable land and undamaged natural systems are both critical and not just fragile, but in decline?

For natural ecosystems, we derive the loss of the carbon cycle, the loss of biodiversity, and the downstream impacts on secondary systems. For example, when logging changes the chemical composition of streams, and releases carbon (Freeman et al. 2025). For how long should we assume, that is, over the years, how much carbon would we lose? In a forever society, it would be forever. We cannot use that duration because no project could ever be approved. We increase costs for biodiversity loss, and determine the carbon capture per acre per year for 30 years, and add the cost of destruction and development in terms of fuel and construction costs. Each case would

be determined on its own facts, but we can present a suitable example, by clearing one acre of forest, for any purpose.

Estimates on the amount of carbon an acre of forest can maintain is dependent on the location and weather, type and age of trees, and the health of the forest ecosystem, which includes invertebrates which help turn fallen wood back into nutrition for the soil. Estimates are from 2–8 metric tons a year. For this quick example, we will use 5 metric tons a year. We should assume 30 years. That would be 150 metric tons of carbon.

Why take the entire 30 years in the front, why not spread the cost over the entire 30 years? It is because the damage is done at the front, and while the damage will persist for 30 years, the project might not.

There is the carbon cost of clearing the land. To determine that, we would need to know about the site. Is it steep? How much leveling will it require? Does some feature of the watershed have to be rerouted or contained? Is it thick soil, or dry, sandy, or rocky soil? Each of those factors, and some that will be suggested by the site itself. Let us assume a relatively flat site that requires only 20 hours of heavy equipment time to fall and remove timber, gouge out the stumps and level the ground. Heavy equipment (Hansen 2024) carries a very large carbon load. In general terms, that equates to 15 liters or 40.2 kg CO_2 per hour, or 804 kg to clear one acre. We can assume one truckload of trees, and two dump truck loads of limbs and stumps. At an estimated 2.55 kilometers per liter, and a 160 kilometers, round trip, times three trips, 482 kilometers. This indicates an estimated 188 liters of diesel, and so 504 kg of carbon dioxide[10] (equivalent). We take those known costs, and apply other carbon costs in the formula. We find 151,308 kg to be the carbon cost, and then add 100%.

Because it would require too much data to properly charge for loss of biodiversity, we can really only account for the carbon, but we can increase it by 100% because a critical and fragile natural resource is being destroyed.

We can also deduct a similar amount for projects which restore arable land designated as damaged beyond the ability to absorb carbon.

[10] https://cfm-calculator.com/biology/calc.php 9/14/25 [15.03.2026].

11.5. Physical development on land and water sites

Like arable land, there were no urban places until human settlement, and all developed land represents land taken from the systems of nature. History shows that, most often, a developed space is built on over and over. The reasons are pragmatic and easy to understand. First, people go where other people are; we are an extremely gregarious species. Next, the locations often have some geographic reasons: mountain passes, sea and river ports, bays and quays, crossroads, and so on. Those are features important to trade and migration, and buildings and facilities are built, used, robbed out for materials, and rebuilt again. Glaciers disappear, rivers dry, bays become silted in, and so, things move about. If the trade routes change, or the climate changes, the flow of energy stops and places die.

Building over the footprint of a previous development will save a project the large input cost of critical, fragile natural resources and related exteriorized costs with developing over arable land, or natural ecosystems.

Even so, a project input must include the carbon used to source and process the materials, and transportation carbon costs, and the actual cost of construction. For example, the carbon cost of lumber (carbon cost of loss of trees, cutting trees, shaping lumber from the log, shipping the lumber), as well as paints glues, hardware and so on. It would require more energy to research each fitting than we can justify, so again, we use "approximations" from what data we do have.

Since error is likely, we seek to move the incidence of error towards protecting the system, and so, the surplus of nature.

11.6. An example of a project EROEI analysis might be like this hypothetical example[11]

We (as an exercise) receive a project proposal from a local entity presenting it on behalf of a committee of individuals. For convenience, we can call it the "Sunrise" project. The property is an abandoned shopping center, partially demolished, which the city owns through foreclosure. The proposal has been reviewed by several

[11] Note: for this section we used these "CO2 calculators" as well as other on-line sources, including AI searches: Environmental Protection Agency, European Rental Association, vCalc (Heckman 2023)

departments, and each has provided either information, or necessary authority, on the project, so we know quite a lot about it. It has been approved, and comes to Risk Management for an analysis of EROEI, and its place in the prime directive: keep the global social system living within the surplus of nature.

Our determination as to the EROEI of the project does not consider the economic viability, which requires a different analysis. We actually do two analyses, the construction and initial operation, and the on-going operation. If the analysis passes the first, it might still fail the second. The third period, deconstruction, may be moot if the project is on-going.

We note immediately that the plan has a carbon reduction pledge, meaning, all participants agree to reduce carbon whenever possible. The goal is to have everyone use only 8 kg carbon a day. This means the food choices will tend toward plant matter (Ritchie 2020), and travel will be minimal, and the water system will be lower pressure, and appliances will be energy rated, and other means of behavior and technology employed to reduce GFGs.

12. Project configuration

The committee of individuals intends to reclaim 17 acres of parking lot and drives, and destruction debris, including remnant building materials, and two small buildings which had been storage and maintenance for the shopping center. The committee proposes to pull up the concrete and tarmac for reclaimed land on 9 acres of paved land and 4 acres of abandoned "green space" around three sides of the parcel, bringing 12 acres back to arable land, in addition 1 acre to a marsh gray water system. There is planned, a central domestic area of 3 acres, and an acre of public access. The plan intends to consolidate the destruction debris and paving surface to small homes, fences, and small animal habitation. Most work will be done by hand, however, one week of heavy equipment is included, to cut the paved portions into useful blocks. New materials, according to the plan, will include lumber, though a source of reclaimed lumber has been identified, and cement, which is carbon expensive.

When the first stage of the plan is completed, expected to take 2–3 years, there

will be 10 houses of 600 square feet. Each will have a roof-water collection system hooked to a concrete tank of 100 gallons, which is filtered. Each will cook with natural gas, already available on the property. They plan to reuse some of the pipes from the previous installation, though they will have to be inspected and tested. Each will have a connection to the city water system when the tanks are empty, and city sewer system, but showers and laundry are communal. Shower and laundry discharge will go to a fat collector and then to the 1 acre sand and biodiverse plants marsh filtration system (Santos et al. 2024). The contract calls for the use of only vegetable soaps and no other chemicals. The water would be used, under a plan approved as sustainable by the appropriate authority, to grow food plants for human consumption, and to raise chickens and rabbits. The small animals are fed from garden scraps, but it is planned that a considerable amount of grains, legumes and silage will be culled from harvest and stored. Chicken and rabbit manure and human urine would provide fertilizer. The plan, in autumn, calls for bicycle carts to harvest fallen leaves in the neighborhood to compost, and to feed to the rabbits.

In five years, the committee of individuals intends to be growing enough food, including beans, peas, wheat, potatoes and truck garden products, with a small amount of animal protein, for thirty people, the maximum population of the project.

The committee of individuals plans to open the public access area to a Saturday market to sell their produce and products from neighboring gardens, craftsmen and service providers.

All items covered by the project, including hand tools, cement, equipment, fresh water services, hardware, septic services, are inventoried, and we can examine them and make our evaluation.

When we consider exteriorized effects, we are most concerned about costs, because second and third order effects are difficult to predict and quantify, and they reduce our return on investment and encourage sustainability debt. However, there are positive effects as well, which are likewise easy to identify but difficult to quantify. For example, a Saturday Market would likely reduce the sales of less sustainably raised food, and might reduce travel time from the neighborhood to a more distant sales point. However, it would be seasonal, and likely, have more success some years than others, since that is how horticulture and agriculture are. In addition, how much

less might people travel, and might they still travel the same distance to the market for soap, not vegetables?

We have already opened the door to guesstimation in our methodology when we seek exteriorized costs, which are complex, are obvious in their existence but not fully quantifiable, and sometimes are only understood in retrospect, postmortem. Do we need to account for this benefit? Would it save a significant amount of carbon emissions?

Taking the long view, we do need to account, because, by giving it a value, it becomes a variable we track; change comes from second and third order effects, and if we record data accurately, trends will emerge which can inform our subsequent analyses. We need to account for this positive benefit, by making a guesstimate, and then simply check the data each year to see how well we did the impossible. We can determine that value when we consider the food the project produces.

Likewise, items like hand tools. We see in the report that the committee of individuals is supported by the community, and they are given, for example, used shovels, picks, iron bars and so, we can accept that the carbon cost of those items has been paid. New tools need a carbon value; used tools do not. Likewise, lumber and other items. Required plumbing is expected to come from salvage plumbing on site, saving a large amount of carbon. Do we have to consider carbon saved on those items? It is proposed that we do not, because their carbon transaction took place when they were new, and we would have accounted for the carbon of new materials, but not credited their use of used tools.

Beneath the pavement is not rich soil, but fine gravel, and stones, which will have to be removed. Our hypothetical project intends to use the gravel to make concrete, which will save a large carbon cost on washing and transportation, and minimizes the impact on rivers and gravel fields.

It will take a great deal of work to turn the newly exposed dirt into soil, but the plan uses all resources, and the leaf collection will help soil develop quickly. Rabbit manure is rich in fibers, and will, slowly over time, enrich the soil.

13. Costs of agriculture

Using animal manure and human urine save a great deal of carbon, since nitrogen, phosphorous and potassium are obtained without mining and transporting, and without the improved but still carbon intensive Haber-Bosch method of obtaining nitrogen. Likewise, the practice saves the cost of dwindling amounts of potash and phosphorous. However, twenty chickens, will only fertilize $2/5^{th}$ of an acre, rabbits probably a similar amount. The urine from one person will fertilize 0.10 acre. With a full population of 30 residents, that is 3 acres. Properly applied, the natural sources from the plan will fertilize about 4 acres. Unfertilized land grows only the most hardy and well suited plants. Some fertilizer will have to be purchased to make all 12 acres produce well. Though 68 kg of amendments per acre is common, the committee likely would not use that much; the project might receive adequate production from much less commercial fertilizer. In addition, if the group purchases animal waste based fertilizers, the carbon cost would be much lower. Since the plan calls for those measures, unless new data contradicts it, we can assume a fertilizer CO_2, N_2O and CH_4 and add 22 kg of amendments for 8 acres, at the value described for fertilizers: 2000 kg per mt of fertilizer, so 352 kg of carbon per year.

The pavement the project pulls up will be, in some cases, woven together with steel. Not all the 17 acres was covered by pavement of asphalt or concrete; four acres were “green belt,” now dead lawns and thickets of living and dry brush. It is not a functioning ecosystem, though it does produce some natural environment. That will be cleared more cheaply, but will still require amendments to produce food crops. The plan calls for wheat planted on those acres by the start of year 2 and ten dwarf fruit trees at the start of year 3. Those crops will absorb more CO_2 than the current fallow land.

We will have to untangle the carbon and resource use for that application. In any case, the largest application will be in year 1, where the plan calls for the pavement to be up and the land cleared.

Adding the 12 acres of arable land and 1 acre of marsh reduces the construction impact by the carbon and biodiversity value per acre. Normally, we have a natural system to evaluate for the new arable land, and the value is placed by that specific

location and the system degraded. In this case, we must assign a value based on the value of the regional ecosystem and the location of the developed area. In our hypothetical case, that would be grassland. Heavy grass absorbs about 1 metric ton per acre per year, much of it below ground. Those acres have been sealed off for the life of the site, but will now start to cycle carbon dioxide again, since row crops and fruit trees also absorb carbon. The reclaimed value of the 12 acres at 1000 kg carbon per acre for 30 years is 360,000 kg of carbon. The one acre of wetland is credited with 1.3 mt carbon sequestering a year (Strum 2019), so 39,000 kg of carbon.

We estimate 1 hour per acres (at 15 liters fuel per hour) of heavy equipment under load to complete the conversion to fallow ground. We can credit the project 15 liters per acre at 2.68 kg carbon per liter times 13 acres, so 522.6 kg carbon deducted from the carbon benefit of the restoration.

Why not simply assume they equate, and charge the project nothing for restoring the land? It is because our prime directive, to live in the surplus of nature, requires us to be as specific as possible. Our methodology is simple and straightforward, but the practice of it is necessarily complex, and already requires a good amount of "guesstimology."

There will also be equipment costs for constructing the residences. The plan calls for five 7.5 hour days at a nominal 12 liters of diesel an hour at 2.68 kg carbon per liter for 1206 kg of carbon. For equipment, mostly a large excavator with a pavement breaker attachment. The property has a well-documented utility map, so that pipes and wire will be salvageable. This expense is critical to the success of the project. Also, we need to account for the carbon transportation costs of the transport delivering the equipment, leaving, returning to collect it, leaving, so 2 trips about 100 km, round trip, at 35[12] liters of diesel per trip, or, 187.6 kg of CO_2. This gives a total carbon cost of the construction equipment of 1393.6 kg carbon; or 2787.2 kg carbon with the 100% penalty.

Cement is also critical to the project (Worrell et al. 2001). The ten houses will be identical, all made of pavement blocks, which are uneven. The cement is for mortar and to cover the inside and outside of the walls to make them smooth. All of the cement comes from sacked materials, except the gravel which will be obtained from

[12] This assumes 40 liters at full load, half the trips, and 30 liters traveling empty, half the trips.

the demolition site. Even so, the houses, the water tanks, and key structural features must come from cement. The project will use an estimated 1600 kg of cement. Not all cement making processes are equally carbon valued. However, we will use an estimate of 0.9 kg carbon for every 1 kg of cement produced for 1440 kg CO_2. However, because cement is such a significant contributor to CO_2, N_2O and other greenhouse gas release, it carries an exteriorized cost of 10%, even though some cements absorb carbon, so 1584 kg carbon.

The small homes would use heat pumps for heating, and cooking would be done over natural gas, which has a main service already installed. Those would each produce greenhouse gases, but the heat pump is more efficient than natural gas for heating, particularly since natural gas leaks, from production to the end user, contribute a significant amount of greenhouse gas emissions. “The population weighted US average results show emission reductions for a heat pump over a furnace to be 38–53% for carbon dioxide, 53–67% for 20-year global warming potential (GWP), and 44–60% for 100-year GWP, with reductions increasing over time” (WCEC 2025).

But, heat pumps leak coolant, also greenhouse gases, and use electricity, which, however it is generated, has some carbon load. We see that the property purchases electricity from a provider who uses solar, wind, hydro and natural gas sources. We can use generalized information (approximately 14 kg carbon per person per day for electricity) and estimate of 8.7 kilograms per person per day for electricity in the project, so 3175.5 kg carbon per person per year.

Water heating is shared for the shower, but individual houses have their own hot water, using on-demand natural gas. With share of common shower, we can estimate 0.2 kg per person per day, so 73 kg per person per year for gas.

As noted, water and sewer use are dramatically reduced by the use of urine (flushing a toilet after urination wastes a lot of water to flush a little water), the use of shower collection and reuse, and the home rain water collector each house has. The average estimated use of water per person in the USA, for example, is 11,000 liters per month per person. We can adjust that to 5,000 liters, in and out, because the houses are small, there are water saving procedures in place, and there is the low carbon pledge in place.

We consider, for each initial or continuing input, the amount of carbon used, the limit and resilience values which might add a percentage of carbon. Those carbon costs have to be included in the annual input.

14. Food

But, what of the food grown? We have not given agribusiness carbon credit for growing food, even though it is both critical to our global system, and fragile in nature, since, as fossil fuel carbon dioxide generation declines, food in the store will become both more expensive and with less variety.

While intensive, carbon based agriculture can produce more food per acre, the Sunrise project intends to practice low impact agriculture, which will have losses to pests and disease, since no pesticides will be used, though chickens are pest eaters. Instead of 1000 kg of wheat which a mechanized farm will produce, the project will likely produce 600 kg of wheat from each of their four acres, and most years should harvest 2400 kg. Since the wheat is planted in with dwarf fruit trees, harvest will be a little difficult, but chickens will catch any lost grains. Further, the plot for the project shows the trees ringing the north side of the field, so as to avoid shading the wheat. The ten fruit trees should produce 40 kg each in a good year, for 400 kg.

Four acres will be in legumes, which should produce 500 kg per acre[13], for 2000 kg. Two acres of potatoes, about 5,000 kg per acre, for 10,000 kg. The remaining two acres are winter squash, which should produce at least 3,000 kg each for 6,000 kg, and a few hundred kg of tomatoes. Eggs, chicken and rabbit should add 250 kg or so. The group could grow large rabbits, netting 4 kg dressed each, and thousands of them, if they had unlimited energy, unlimited food. Realistically, they could harvest a few dozen rabbits, a dozen chickens, and lots of eggs without spending too much carbon on feed.

If things go well, that is, if the weather does not turn rapidly dry or rapidly wet at inopportune times, they will harvest approximately 21 metric tons, of food. However, farmers have always experienced ill-timed weather, and now, ill-timed weather will

[13] https://aggie-horticulture.tamu.edu/smallacreage/crops-guides/vegtables/dry-beans/ [16.03.2026].

become increasingly common. Even so, they should produce enough food to meet their goals most years.

Credit on food: 20%, the cost of travel. We cannot credit the project with growing food, but we can give them a carbon value by figuring the carbon they save. Transportation alone contributes 20% to agricultural greenhouse emissions (Li et al. 2022). In addition, their food is produced in a low-carbon emissions, biodiversity sparing system, but this was compensated for because they paid a lower fertilizer cost. Transportation is a carbon saving that is easy to identify, quantify, and track.

We can see that these residents will do a lot of physical activity. We can reasonably assign 2.4 kg of food per person per day or, about 876 kg of food per person annually, so a maximum expected population use of total use 26,000 kg of food per year.

Not all food kgs are equal, since many food products are mostly water. A pound of potatoes will provide less food than a pound of dried beans.

Readily available sources suggest carbon emissions in CO_2 kg per kg of food for these sources the Sunrise community hopes to grow: peas and legumes generally, 1 to 1; wheat; 2.5; eggs 4; poultry 6. We do not know in what measure each person will consume each food, but we can bang out a workable number assuming they eat an equal amount of all, and propose 3.7 kg as the average carbon cost per kg of food. For a year's consumption of 26,000 kg of food, the project gets a negative cost of 20% or 19240 kg.

Regarding the carbon saving of the project's Saturday market, for the second year we will estimate they sell 1000 kg of food at 3.7 kg carbon, and we can give them a credit of 740 kg; however, our intention is to gather information and fine tune our estimate as time goes on.

15. Project resilience and deconstruction costs still need to be addressed

Does the project suggest some resilience against climate change? We first have to context the project in the larger social environment. It is in a decaying part of a small city, and because rents are low, it is likely to be occupied for some time. If the weather suddenly changed, grew warmer, or worse, became more unpredictable, then the

project would be effected as everyone in the region or nation would be. However, the homes, if utilitarian, are durable, and the solutions they would have in place would have productive value even if temporarily neglected. They do not contain large amounts of toxic materials, that means there would be little or no demolition costs. In our hypothetical case, we will suggest there were no demolition costs assigned when it was built, and what demolition there has been was simply to remove the furnishings, salvage doors and wires and pipes, and glass, and then use excavators to tear the buildings down, and send them in trucks as fill or to rest in some valley in the dump. The environment paid the carbon cost on that. Our project is far closer to a low carbon state, even if abandoned.

15.1. Project EROEI

The analysis shows that even this carefully selected example has a difficult time to avoid wandering from the shifting basin of sustainability. Though the project was well designed, the goal of EROEI of 1:1, and the on-going goal of 8 kg of carbon a day could not be reached. Instead, the project fell short with an ongoing EROEI of 0.65.

Largely, it was energy that kept the group above the desired goals. However, there is no river to wash and do laundry, nor cow dung or fallen wood to cook over and heat with, carbon expenditures for those activities is mandatory. We keep in mind that we have a goal of keeping society going, and shutting down all fossil fuel energy will cause it to crash, and too suddenly reducing the complexity of the Forever Society would likewise bring about a crash.

The project had a sound construction EROEI of 91.16, contrary to most projects, because we designed it to reduce the carbon cost, on lumber, for example. In determining various inputs, we typically selected a modest value; for example, they might grow more wheat than predicted, though without spending more on fertilizer, we cannot guess how.

Further, the daily carbon cost of 12.22 kg carbon per person is well below the surrounding neighborhood and well below the US average of 39 kg a day. Approving the project would encourage other projects designed specifically to reduce carbon emissions.

We propose approving the project with an annotation of how far they missed a sustainable goal, and a caution to further reduce carbon emissions.

15.2. EROEI of the entire Forever Society

Again, as an exercise, we will review changes in a few obvious variables. They are atmospheric CO_2; GHG emissions in CO_2 equivalent, and the degradation of the surplus of the resources which are critical to us; arable land, forest land, grasslands, wetlands, and fresh water.

We will use what data we can find, but it is important to remember that no one actually knows the value of most of these. Atmospheric GHG is easier to capture, (Greenhouse gases in CO_2 equivalent increased from 51.8 billion metric tons in 2013 to 53.2 in 2024), but most other variables are not.

15.2.1. Data difficulty

A good example would be grasslands (Zhang et al. 2025). That category would include prairies, pampas, alpine meadows, savannas, steppes, and all other kinds of landscapes which are predominately covered in grass of one sort or another, and there are between 11,500 and 13,000 species of grass. As a result of all that variety, there are no clearly defined parameters for the loss of grassland. We did obtain a number, which we will use, but even if it were accurate, we still cannot, at this point, assess the entire carbon load. How was the grassland lost? Bulldozers, we have carbon value for that, but how much grassland is lost to climate change, pollution, and other degrading events? We cannot directly account for those.

14.5.2. Grasslands

We accept that at least 150 million hectares, or 370,658,000 acres, of grasslands have been lost between 2001 and 2023[14], which we can average, and charge at 1.3 mt of carbon per acre a year. The percentage of loss is represented by that percentage of the carbon cost of the project.

[14] https://www.fao.org/statistics/highlights-archive/highlights-detail/land-statistics-2001-2023.-global--regional-and-country-trends/en [16.03.2026].

15.2.3. Loss of arable land?

According to the United Nations Convention to Combat Desertification (UNCCD) data the world lost at least 100 million hectares of healthy and productive land each year from 2015 to 2019[15].

In discussion we have determined that the carbon value loss of arable land was dependent on the ecological type of land lost and the carbon expended converting that land to arable land. Some of the land was drained wetlands; some was plowed grasslands, much of it was forest lands. For this exercise we will arbitrarily replace forest land with arable land, including the carbon cost of equipment. Sometimes forest land is simply burned to create arable land, but that releases even more emissions. We will use the value of the acre of forest land we considered.

15.2.4. Forest losses

The rate of deforestation for the most recent year is 10.9 million hectares (about 27 million acres) per year (FAO 2025) (some sources say 8.1 million in 2025, but to introduce caution, we will use 10.9 million). Humans are no longer the leading direct disturbance to wild lands, instead wildfires, droughts, wide ranging disease agents and other effects of climate change are (Qiu et al. 2025), but we will attribute both to humans. We will use the formula for one acre of woodland to evaluate the loss. Each acre lost carries a debt of 151308 kg.

14.2.5. Wetlands

It is estimated that over the last 50 years 411 million hectars, or 1,016,999,000 acres of wetlands have been lost, from drainage and fill, but many from drying conditions. Each acre sequesters 1.34 mt of carbon a year. Again, we lose the ability to determine the carbon cost of destroying the wetlands, but will capture the carbon sequestering loss, and the percentage of change over the described period. That percentage is applied to the carbon cost of the project.

[15] https://data.unccd.int/ [16.03.2026].

15.2.6. Fresh water

The world lost 1,200 cubic kilometers of water between 2015 and 2023 (NASA Earth Obs. 2024). An easy if not very precise value is arrived by taking the average and multiplying it by the cost for lost fresh water, .04 kg per liter.

16. Conclusion

The term "sustainable development" is an oxymoron: we either employ methodologies to judge the existential risks of a project, or we develop our world to death. Fossil fuels have accelerated our population growth and the complexity of the culture we use to mediate nature, such as agriculture, and loss of that energy will result in a loss of social complexity. Carbon and greenhouse gas emissions are the yardstick by which we can estimate the rapidity of climate change, and analyse and constrain emissions and other forms of ecosystem damage.

If an effort is made to identify critical ecosystem services and account in some measure for the loss of those critical ecosystems before projects are undertaken, risk can be avoided.

The final data makes it clear: we are far from a Forever Society. Unless risk management methodologies are implemented to reduce carbon emissions, the critical resources of our survival will be overwhelmed.

The consequences of that are grim.

References

Alcott B. (2008), Historical overview of the Jevons paradox in the literature, in: The Jevons paradox and the myth of resource efficiency improvements, Polimeni J.M., Mayumi K., Giampietro M. (eds.), Earthscan, pp. 7–78, https://uberty.org/wp-content/uploads/2015/08/John_M._Polimeni_Kozo_Mayumi_Mario_Giampietro.pdf [15.03.2026].

Alfaro-Núñez A., Astorga D., Cáceres-Farías L. et al. (2021), Microplastic pollution in seawater and marine organisms across the Tropical Eastern Pacific and Galápagos, "Sci. Rep.", vol. 11, 6424, https://doi.org/10.1038/s41598-021-85939-3

Bardi U., Bierwirth P., Huang K.-W., McIntyred J. (2025), Carbon dioxide as a pollutant: the risks on human health and the stability of the biosphere, "Environmental Sciences: Advances Issue", no. 9, https://doi.org/10.1039/D5VA00017C.

Bartlett A.A. (1994), Arithmetic, population, and energy (The forgotten fundamentals of the energy crisis), Academic Media Services, University of Colorado.

Besnard S., Heinrich V.H.A., Carvalhais N. et al. (2025), Global covariation of forest age transitions with the net carbon balance, "Nature Ecology & Evolution", vol. 9, pp. 1848–1860, https://doi.org/10.1038/s41559-025-02821-5.

Bologna M., Aquino G. (2020), Deforestation and world population sustainability: a quantitative analysis, "Sci Rep", vol. 10, 7631, https://doi.org/10.1038/s41598-020-63657-6

Boserup E. (1985), The impact of scarcity and plenty on development, in: Hunger and history: the impact of changing food production and consumption patterns on society, Rotberg R.I., Rabb T.K. (eds.), Cambridge University Press, New York, pp. 185–210.

Brockerhoff E.G., Barbaro L., Castagneyrol B. et al. (2017), Forest biodiversity, ecosystem functioning and the provision of ecosystem services, "Biodivers. Conserv.", vol. 26, pp. 3005–3035, https://doi.org/10.1007/s10531-017-1453-2.

Carroll L. (1871), Through the looking-glass, and what Alice found there, Macmillan, New York.

Chandrasekhar A., Dunne D., Viglione G. (2022), UN land report. Five key takeaways for climate change, food systems and nature loss, "Nature", 27 April, https://www.carbonbrief.org/un-land-report-five-key-takeaways-for-climate-change-food-systems-and-nature-loss/.

Coco E., Iovita R. (2025), Agent-based simulations reveal the possibility of multiple rapid northern routes for the second Neanderthal dispersal from Western to Eastern Eurasia, "PLoS One", vol. 20 no. 6, e0325693, https://doi.org/10.1371/journal.pone.0325693.

Cohen J.E., How many people can Earth support? W. W. Norton & Company, September 17, 1996 ISBN-10 : 0393314952 ISBN-13 : 978-0393314953

Cornejo P., Santana M., Hokanson D., Mihelcic J., Zhang Q. (2014), Carbon footprint of water reuse and desalination. A review of greenhouse gas emissions and estimation tools, "Journal of Water Reuse and Desalination", vol. 4, no. 4, pp. 238–252, https://doi.org/10.2166/wrd.2014.058238.

Cowie R.H., Bouchet P., Fontaine B. (2022), The Sixth Mass Extinction: fact, fiction or speculation?, "Biol. Rev.", vol. 97, pp. 640–663, https://doi.org/10.1111/brv.1281.

Cox M.P., Morales D.A., Woerner A.E., Sozanski J., Wall J.D. et al. (2009), Autosomal resequence data reveal late stone age signals of population expansion in sub-Saharan African foraging and farming populations, "PLoS ONE", vol. 4 no. 7, e6366 DOI: 10.1371/journal.pone.0006366.

Danger M., Daufrense T., Lucas F., Pissard S., Lecroise G. (2008), Does Liebig's law of the minimum scale up from species to communities?, http/:doi/10.1111/j.1600-0706.2008.16793.x.

DeVita L. (2023), Crash course in prediction and mitigation for a crashing system: a complex biocultural sociological perspective of sudden social decline, Central European Review of Economics and Management", vol. 7 no. 1, pp. 31–61.

Doney S.C., Shallin Busch D., Cooley S.R., Kroeker K.J. (2020), The impacts of ocean acidification on marine ecosystems and reliant human communities, "Annual Review of Environment and Resources", vol. 45, pp. 83–112, https://doi.org/10.1146/annurev-environ-012320-083019.

EDGAR (Emissions Database for Global Atmospheric Research) (2025), https://edgar.jrc.ec.europa.eu/report_2025?vis=ghgpop#emissions_table [16.03.2026].

FAO (2025), Global Forest Assessment, https://openknowledge.fao.org/server/api/core/bitstreams/2dee6e93-1988-4659-aa89-30dd20b43b15/content/cd6709en.html 11/14/2025 [16.03.2026].

Ferentinos G., Gkioni M., Geraga M., Papatheodorou G. (2012), Early seafaring activity in the southern Ionian Islands, Mediterranean Sea, "Journal of Archaeological Science", vol. 39 no. 7, pp. 2167–2176, https://doi.org/10.1016/j.jas.2012.01.032.

Filonchyk M., Peterson M.P., Zhang L., Hurynovich V., He Y. (2024), Greenhouse gases emissions and global climate change: examining the influence of CO2, CH4, and N2O, "Science of The Total Environment", vol. 935, https://doi.org/10.1016/j.scitotenv.2024.173359.

Forest Declaration Assessment (2025), https://forestdeclaration.org/resources/forest-declaration-assessment-2025, 13 October.

Freeman E.C., Emilson E.J.S., Webster K.L., Dittmar T., Tanentzap A.J. (2025), Logging disrupts the ecology of molecules in headwater streams, "Proc. Natl. Acad. Sci. U.S.A.", vol. 122 no. 35, e2409104122, https://doi.org/10.1073/pnas.2409104122.

Gauri S. (2019), Land degradation and challenges of food security, "Review of European Studies", vol. 11 no. 1, pp. 63–63, doi:10.5539/res.v11n1p63.

Gebremariam G.H. (2024), A systematic review of insect decline and discovery: trends, drivers, and conservation strategies over the past two decades, https://doi.org/10.1155/2024/5998962.

Gerten D., Braun J., Breier J., Lucht W., Tobian A., Stenzel F. (2025), A software package for assessing terrestrial planetary boundaries, https://doi.org/10.1016/j.oneear.2025.101341.

Grant L., Vanderkelen I., Gudmundsson L. et al. (2025), Global emergence of unprecedented lifetime exposure to climate extremes, "Nature", vol. 641, pp. 374–379, https://doi.org/10.1038/s41586-025-08907-1.

Guzmán Bloise A., Pöhlker C., Chiliński M.T., Aardema H.M., Cybulski J.D. et al. (2025), Unprecedented suppression of Panama's Pacific upwelling in 2025, "Proc. Natl. Acad. Sci. U.S.A.", vol. 122 no. 36, e2512056122, https://doi.org/10.1073/pnas.2512056122.

Hajdu, L. H., Meesters, A. G. C. A., Dolman, A. J., & Friend, A. D. (2025). Deforestation could push Amazonia close to a tipping point under future climate change. Geophysical Research Letters, 52, e2024GL108304. https://doi.org/10.1029/2024GL108304.

Tverberg G. (2018), Energy return on energy invested—Prof. Charles Hall's comments, 12 April, https://ourfiniteworld.com/2018/04/12/energy-return-on-energy-invested-prof-charles-halls-comments/ [17.03.2026].

Hall C.A.S., McWhirter T. (2023), Maximum power in evolution, ecology and economics, https://doi.org/10.1098/rsta.2022.0290.

Hansen A.H., Schmidt L. (2024), Large construction machines are huge, overlooked climate culprits, 04 September, https://www.energy.aau.dk/large-construction-machines-are-huge-overlooked-climate-culprits-n119037 [15.03.2026].

Heckman K. (2023), CO2 from Diesel Fuel, vCalc, 31 August, https://www.vcalc.com/wiki/MichaelBartmess/CO2-from-Diesel-Fuel.

Heihsel M., Lenzen M., Malik A., Geschke A. (2019), The carbon footprint of desalination: an input-output analysis of seawater reverse osmosis desalination in Australia for 2005–2015, "Desalination", vol. 454, pp. 71–81, https://doi.org/10.1016/j.desal.2018.12.008.

Hiddink J.G., Kaiser M.J. (2005), Implications of Liebig's law of the minimum for the use of ecological indicators based on abundance, "Ecography", vol. 28, pp. 264–271, https://doi.org/10.1111/j.0906-7590.2005.04063.x.

Hrishikesh A. Chandanpurkar et al. (2025), Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise, "Sci. Adv.", vol. 11, eadx0298, doi:10.1126/sciadv.adx0298.

Hultgren A., Carleton T., Delgado M., Gergel D.R., Greenstone M. et al. (2025), Impacts of climate change on global agriculture accounting for adaptation, "Nature", vol. 642, pp. 644–652, https://doi.org/10.1038/s41586-025-09085-w

Jantsch E. (1976), Evolution and consciousness. Human systems in transition, Addison-Wesley, Reading Ma, pp. 93–130.

Junker R.R., Farwig N. (2025), Microbial conservation is essential for sustaining ecosystem functions and services, "Proc. Natl. Acad. Sci. U.S.A.", vol. 122 no. 38, e2503013122, https://doi.org/10.1073/pnas.2503013122.

Klein Goldewijk K., Beusen A., Janssen P., HYDE 3.1: long-term dynamic modeling of global population and built-up area in a spatially explicit way, Netherlands Environmental Assessment Agency (MNP), Bilthoven.

Lawrence Deborah , Coe Michael , Walker Wayne , Verchot Louis , Vandecar Karen ;The Unseen Effects of Deforestation: Biophysical Effects on Climate; Frontiers in Forests and Global Change Volume 5 – 2022 https://www.frontiersin.org/journals/forests-and-global change/articles/10.3389/ffgc.2022.756115 DOI 10.3389/ffgc.2022.756115 ISSN=2624-893X

Lenton T.M., Laybourn L., Armstrong McKay D.I., Loriani S., Abrams J.F. et al. (2023), Global tipping points report 2023: Summary report, in: The global tipping points report 2023, University of Exeter, Exeter, UK.

Leonhardt E.R. (1884), Die internationale elektrische Ausstellung Wien 1883: unter besonderer Berücksichtigung der Organisation, sowie der baulichen und maschinellen Anlagen, Craz & Gerlach, Freiberg i.S., http://www.e-rara.ch/zut/22499137.

Li M., Jia N., Lenzen M. et al. (2022), Global food-miles account for nearly 20% of total food-systems emissions, "Nat. Food", vol. 3, pp. 445–453, https://doi.org/10.1038/s43016-022-00531-w.

Li Y., Meng L., Richardson A.D., Lee X., Menzel A., Mao J., Diehl J.L., Wang A. (2025), Cooling outweighs warming across phenological transitions in the Northern Hemisphere, "Proc. Natl. Acad. Sci. U.S.A.", vol. 122 no. 37, e2501844122, https://doi.org/10.1073/pnas.2501844122.

Lucas A. (2006), Wind, water, work: ancient and medieval milling technology, Brill Publishers, Leiden.

MacLeod M., Arp H.P.H., Tekman M.B., Jahnke A. (2021), The global threat from plastic pollution, "Science", vol. 373 no. 6550, pp. 61–65, doi:10.1126/science.abg543.

Malthus R. (1798), An essay on the principle of population as it affects the future improvement of society, with remarks on the speculations of Mr. Goodwin, M. Condorcet and other writers, 1 ed., J. Johnson in St Paul's Church-yard, London, Internet Archive [20.06.2015].

Marshall A. (1920), Principles of economics, 8th ed., Macmillan, London.

Mauritsen T., Tsushima Y., Meyssignac B., Loeb N.G., Hakuba M., Pilewskie P. et al. (2025), Earth's energy imbalance more than doubled in recent decades, "AGU Advances", vol. 6, e2024AV001636, https://doi.org/10.1029/2024AV001636.

McClelland S.C., Bossio D., Gordon D.R. et al. (2025), Managing for climate and production goals on crop-lands, "Nat. Clim. Chang.", vol. 15, pp. 642–649, https://doi.org/10.1038/s41558-025-02337-7.

McConnell J.R., Wilson A.I., Stohl A., Arienzo M.M., Chellman N.J. et al. (2018), Lead pollution recorded in Greenland ice indicates European emissions tracked plagues, wars, and imperial expansion during antiquity, "Proc. Natl. Acad. Sci. U.S.A.", vol. 115 no. 22, 5726-5731, https://doi.org/10.1073/pnas.1721818115.

Mengqi Z., Sun J., Wang Y., Li Y., Duo J., State-of-the-art and challenges in global grassland degradation studies, "Geography and Sustainability", vol. 6 no. 2, 100229, https://doi.org/10.1016/j.geosus.2024.08.008.

Mgelwa A.S., Ngaba M.J., Hu B., Gurmesa G.A., Godfrey Mwakaje A. et al. (2025), Meta-analysis of 21st century studies shows that deforestation induces profound changes in soil characteristics, particularly soil organic carbon accumulation, "Forest Ecosystems", vol. 12, 100257, https://doi.org/10.1016/j.fecs.2024.100257.

Motesharrei S., Rivas J., Kalnay E. (2014), Human and nature dynamics (HANDY): Modeling inequality and use of resources in the collapse or sustainability of societies, "Ecological Economics", vol. 101, pp. 90–102.

NASA Earth Observatory (2024), Global freshwater abruptly declines, 23 November, https://earthobservatory.nasa.gov/images/153608/global-freshwater-abruptly-declines [16.03.2026].

Nature Climate Change (2024), Research briefing. Deep-ocean currents weaken in a warming climate, "Nat. Clim. Chang.", vol. 14, pp. 905–906, https://doi.org/10.1038/s41558-024-02076-1.

Odum H.T. (1995), Self-organization and maximum empower, in: Maximum power: the ideas and applications of H.T. Odum, Hall C.A.S. (ed.), Colorado University Press, Colorado.

Ohenhen L.O., Zhai G., Lucy J. et al. (2025), Land subsidence risk to infrastructure in US metropolises, "Nat Cities", vol. 2, pp. 543–554, https://doi.org/10.1038/s44284-025-00240-y.

Opitz Stapleton S., Nadin R., Watson C., Kellet J. (2017), Climate change, migration and displacement.

Ostwald W. (1912), Die Energetische imperativ, Academische Verlag, Leipzig.

Panagopoulos A., Haralambous K.-J. (2020), Environmental impacts of desalination and brine treatment. Challenges and mitigation measures, "Marine Pollution Bulletin", vol. 161 part B, 111773, https://doi.org/10.1016/j.marpolbul.2020.111773.

Peñuelas J., Nogué S. (2023), Catastrophic climate change and the collapse of human societies, "National Science Review", vol. 10 no. 6, nwad082, https://doi.org/10.1093/nsr/nwad082.

Prăvălie R., Patriche C., Borrelli P., Panagos P., Roșca B. et al. (2021), Arable lands under the pressure of multiple land degradation processes. A global perspective, "Environmental Research", vol. 194, 110697, https://doi.org/10.1016/j.envres.2020.110697.

Prigogine I. (1976), Order through fluctuation self-organization and social evolution and consciousness, https://www.organism.earth/library/document/order-through-fluctuation.

Qiu S., Zhu Z., Yang, X. et al. (2025), A shift from human-directed to undirected wild land disturbances in the USA, "Nat. Geosci.", vol. 18, pp. 989–996, https://doi.org/10.1038/s41561-025-01792-3.

Quinton J.N., Fiener P. (2023), Soil erosion on arable land. An unresolved global environmental threat, "Progress in Physical Geography: Earth and Environment", 48(1), 136-161. https://doi.org/10.1177/03091333231216595 (Original work published 2024)

Rasul K., Bruckner M., Mempel F., Trsek S., Hertwich E.G. (2024), Energy input and food output. The energy imbalance across regional agrifood systems, "PNAS Nexus", vol. 3 no. 12, doi:10.1093/pnasnexus/pgae524.

Ribalet F., Dutkiewicz S., Monier E. et al. (2025), Future ocean warming may cause large reductions in Prochlorococcus biomass and productivity, "Nat. Microbiol.", vol. 10, pp. 2441–2453, https://doi.org/10.1038/s41564-025-02106-4.

Richardson K., Steffen W., Lucht W., Bendtsen J., Cornell S.E., Donges J. F., Drüke M., Fetzer I., Bala G. et al. (2023), Earth beyond of nine planetary boundaries, "Science Advances", vol. 9 no. 37, doi: 10.1126/sciadv.adh24.

Ritchie H. (2020), Less meat is nearly always better than sustainable meat, to reduce your carbon footprint, OurWorldinData.org, https://ourworldindata.org/less-meat-or-sustainable-meat [16.03.2026].

Rockström J., Steffen W., Noone K., Persson Å., Chapin F.S. III, Lambin E., Lenton T. et al. (2009), Planetary boundaries: exploring the safe operating space for humanity, "Ecology and Society", vol. 14 no. 2, https://doi.org/10.5751/ES-03180-140232.

Rodell M., Barnoud A., Robertson F.R. et al. (2024), An abrupt decline in global terrestrial water storage and its relationship with sea level change, "Surv Geophys", vol. 45, pp. 1875–1902, https://doi.org/10.1007/s10712-024-09860-w.

Rose K.C., Ferrer E.M., Carpenter S.R. et al. (2024), Aquatic deoxygenation as a planetary boundary and key regulator of Earth system stability, "Nat. Ecol. Evol.", vol. 8, pp. 1400–1406, https://doi.org/10.1038/s41559-024-02448-y.

S&P (2024), Global Sustainable 1. The top externalities of the global market unpriced environmental costs.

Santos J., Rodrigues S., Magalhães M., Rodrigues K., Pereira L., Marinho G. (2024), A state-of-the-art review (2019–2023) on constructed wetlands for greywater treatment and reuse, "Environmental Challenges", vol. 16, 100973, https://doi.org/10.1016/j.envc.2024.100973.(https://www.sciencedirect.com/science/article/pii/S2667100024001392).

ScienceDaily (2018), University of Wisconsin-Madison: Ancient farmers spared us from glaciers but profoundly changed Earth's climate, ScienceDaily, 6 September, www.sciencedaily.com/releases/2018/09/180906141507.htm.

Shahzad M.W., Burhan M., Ang L., Ng K.C. (2017), Energy-water-environment nexus underpinning future desalination sustainability, "Desalination", vol. 413, pp. 52–64, https://doi.org/10.1016/j.desal.2017.03.009.

Shrestha U.B., Chaudhary T., Shrestha T. (2025), Chapter 20. Major forest biodiversity and ecosystem goods and services, in: Forests for Inclusive and Sustainable Economic Growth, Purabi S., Kumar A., Khan M.L., Lei X. (eds.), Elsevier, pp. 269–280, https://doi.org/10.1016/B978-0-443-31406-3.00020-5.

Smalling K.L., Romanok K.M., Bradley P.M., Morriss M.C., Gray J.L. et al. (2023), Per- and polyfluoroalkyl substances (PFAS) in United States tapwater: comparison of underserved private-well and public-supply exposures and associated health implications, "Environment International", vol. 178, 108033, https://doi.org/10.1016/j.envint.2023.108033.

Smil V. (2017), Energy and civilization: a history, MIT Press, Cambridge, Ma.

Smithsonian Department of Botany, Grass Research, https://naturalhistory.si.edu/research/botany/research/grass-research [16.03.2026].

Steffen W., Richardson K., Rockström J., Cornell S.E., Fetzer I., Bennett E.M., Biggs R. et al. (2015), Planetary boundaries. Guiding human development on a changing planet, "Science", vol. 347 no. 6223, 1259855, https://doi.org/10.1126/science.1259855.

Strona G., Bradshaw C.J.A. (2018), Co-extinctions annihilate planetary life during extreme environmental change, "Scientific Reports", vol. 8 no. 1, doi: 10.1038/s41598-018-35068-1.

Strum M. (2019), Stewardship of wetlands and soils has climate benefits, NRDC, https://www.nrdc.org/bio/melanie-sturm/stewardship-wetlands-and-soils-has-climate-benefits [16.03.2026].

Thompson R.C. et al. (2024), Twenty years of microplastic pollution research—what have we learned?, "Science", vol. 386, eadl2746, doi:10.1126/science.adl2746.

Tian H., Xu R., Canadell J.G. et al. (2020), A comprehensive quantification of global nitrous oxide sources and sinks, "Nature", vol. 586, pp. 248–256, https://doi.org/10.1038/s41586-020-2780-0.

UN (2024), UN World Water Development Report 2024, Water for Prosperity and Peace, UNESCO World Water Assessment Programme.

UNEP (United Nations Environment Programme) (2023), Nature Risk Profile: a methodology for profiling nature related dependencies and impacts, https://resources.unep-wcmc.org/products/WCMC_RT496 [07.02.2025].

Van Holt T., Binford M.W., Portier K.M., Vergara R. (2016), A stand of trees does not a forest make. Tree plantations and forest transitions, "Land Use Policy", vol. 56, pp. 147–157.

Van Valen L. (1973), A new evolutionary law, University of Chicago, https://www.scribd.com/document/609889927/A-new-evolutionary-law.

Wang Y., Morosuk T., Cao W. (2024), Carbon footprint of seawater desalination technologies: a review, "J. Energy Resour. Technol.", vol. 146 no. 8, 080801, https://doi.org/10.1115/1.4065251.

WCEC, Analysis of greenhouse gas emissions from residential heating technologies in USA https://wcec.ucdavis.edu/analysis-of-greenhouse-gas-emissions-from-residential-heating-technologies-in-usa/ [10.07.2025].

Worrell E., Price L., Martin N., Hendriks C., Meida L. (2001), Carbon dioxide emissions from the global cement industry, "Annual Review of Environment and Resources", vol. 26, pp. 303–329, https://doi.org/10.1146/annurev.energy.26.1.303.

Zhang Y. (2024), The importance of fresh water. A vital resource for life, "J. Aquacult. Eng. Fish. Res.", vol. 10 no. 9.

https://aggie-horticulture.tamu.edu/smallacreage/crops-guides/vegtables/dry-beans/ [16.03.2026].

https://cfm-calculator.com/biology/calc.php 9/14/25 [15.03.2026].

https://data.unccd.int/ [16.03.2026].

https://equipmentcalculator.org/en/era-equipment-co2-calculator [15.03.2026].

https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator [15.03.2026].

https://www.fao.org/statistics/highlights-archive/highlights-detail/land-statistics-2001-2023.-global--regional-and-country-trends/en [16.03.2026].

https://www.worldometers.info/world-population/ [18.06.2025].