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The Affluence–Technology Connection in the Struggle for Sustainability

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Engaging Environmental Violence

Technology will play a role in addressing environmental violence. Some common technological aims include: more equitable access to cleaner and safer industrial techniques; wider deployment of pollution safeguards; and the transition of energy infrastructure away from fossil fuels and toward batteries and renewables. Of course, alternative technologies do not address many of the structural and cultural factors involved in generating environmental violence. Shifting from one mechanism to another, or one material to another, entails a shift in economic context, but guarantees nothing about whether this new context will be more equitable, or even ecologically responsible. We propose that, in order for technology deployment to be truly appropriate to the task of reducing environmental violence, economic affluence must be an equally primary factor of concern. In this article, we introduce the "affluence–technology connection" and provide several different contexts and perspectives to support the concept. These include appropriate technology efforts in Ladakh, India, the carbon footprint of alternative transportation technologies, and the true impact of service sector versus industrial sector activities. These lead us to a fairly simple conclusion: Achieving a lower-violence future means seeking *appropriate affluence* alongside appropriate and sustainable technologies.

7.1 Introduction

The economy is a subsystem of the environment, that is, the physical Earth and its daily dose of sunlight. By turning resources from this macro-system into products and services, humans meet their needs and create new ones. We use "technology" to drive this process and also to deal with the consequences. Waste and pollution are captured and stored away from human exposure; resource use becomes more efficient, allowing greater swaths of people to afford technological benefits; and automation removes humans from physical harm and drudgery, improving the quality of life. However, technological advancement also tends to come with greater power over the Earth: larger and more powerful machines capturing more materials and expanding humanity's reach further into ecological territory. We may use technology to protect *local* environments, but we also use it to provide greater levels of affluence. As we ratchet up material comforts and services for ourselves, we draw on the *total* environment – the one global ecology shared by all life.

In this article, we confront technology's mixed contributions to this conundrum, asking whether and how technology may be guided toward true sustainability. First, we discuss the famous IPAT (Impact Population Affluence Technology) equation, relating environmental impact to population, affluence, and technology parameters (Section 7.2). This establishes the foundation for exploring the *affluence–technology connection*, a crucial intersection on the uncertain path to ecological sustainability. Many fields of thought, analytical approaches, and ancient wisdom can be found at this intersection and we touch on several.

We go to Ladakh, a region of the Himalayas, to explore a tradition of *appropriate technology* that differs from the typical developmental idea of the concept (Section 7.3). There, a fusion of traditional and modern technologies demonstrates a promising type of appropriateness that incorporates certain global technologies into a slower, more land-based way of life. Ladakh sets an example, but it is one not easily emulated in the Global North, where high speed and constant material turnover are the norm. What would it look like to cultivate affluence-limiting technology in this context?

To get at this question, we then explore the limits and opportunities of technology, focusing on the transportation (Section 7.4) and service sectors (Section 7.5). Finally, in Section 7.6, we call for technological "progress" to be pursued with slower speeds, greater deliberation, and lower consumption as target metrics. On such a path, we can enjoy technological breakthroughs and a thriving environment, within the bounds of *appropriate affluence.*

7.2 The Affluence–Technology Connection

In the spring of 1903, Wilbur and Orville Wright, two brothers who ran a bicycle production and repair shop in Ohio, mounted a four-cylinder engine onto the massive glider they had been testing on windy Atlantic Ocean beaches [1]. They used the gliding experience to develop a wing-warping mechanism for managing the natural lift provided by winds. Now they would provide on-board lift capability with a pair of propellers powered by an engine. The engine was designed and built with tools available at their bicycle shop and was

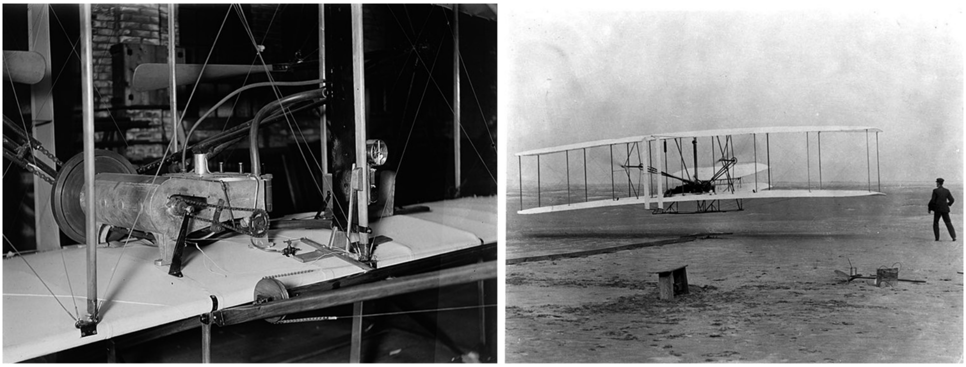

Figure 7.1 Wright Flyer Photographs (L) Custom-built 8-horsepower engine [3]; (R) Famous first flight [4]

made significantly lighter than normal with the purchase of an engine block made entirely of aluminum. This metal had only recently become affordable thanks to the spread of electricity generation, electrolysis being the key step in the new aluminum-smelting process [2]. In December 1903 the brothers would record their famous first flight over the sands of Kitty Hawk, North Carolina (Figure 7.1).

This brief history describes two bicycle mechanics and their innovative leap into a new, higher-speed realm of transportation. It is a classic tale of ingenuity and discovery that changes the course of human events. Or perhaps that moment of innovation was more inevitable than monumental. Several technological advances converged at that time so that powered human flight was finally materially and energetically possible; it was being experimented with in several places across the world at that time [5]. Today, almost 120 years later, powered airplanes dot the sky above every major city in the world and flying is a normal and expected part of both personal and professional lives. International travel has, in turn, globalized our lives, but it has grown up alongside the globalization of pollution as well. We now live in an age where the byproducts of human activity are encroaching on global ecological functions, such as climate regulation, temperature, and the oceanic chemical balance [6].

The Wright brothers' story is a reminder that past approaches to technological progress – while scientifically sound and physically impressive – may no longer fit with the socio-ecological realities of today. Mainstream characterizations of "sustainable technology" still largely praise the kind of convergent efficiency improvements from which the Wrights benefited in 1903: more efficient methods of material extraction and manipulation; more rapid experimentation and information sharing; and the exploitation of new energetic capabilities. While this combination of factors could combine to lessen our demands on the Earth, their effect on affluence – delivering faster and higher quantities of goods and services – tends to outdo the potential gains.[1] This affluence–technology connection lies at the root of our global environmental conundrum.

7.2.1 Framing Technology's Role in Sustainability

A common framework for consideration of the human-Earth system is the IPAT decomposition in which:

$$\text{Impact} = \text{Population} \times \text{Affluence} \times \text{Technology}$$

or

$$\text{Impact} = (\#\text{ of people}) \times \left(\frac{\text{activity}}{\text{person}}\right) \times \left(\frac{\text{impact}}{\text{activity}}\right)$$

The IPAT identity evolved from a debate among environmental thinkers in the 1970s and 80s centered on the question of what driver was most responsible for global ecological degradation [10, 11]. The debate largely focused on population questions versus "faulty technology" whereas affluence was considered as an indicator of societal progress or development [12]. Indeed, many presentations of the IPAT equation use GDP per capita as the Affluence metric, GDP being the World Bank's primary metric for economic health [13].

The structure of the IPAT equation is such that, in order to reduce impact from one period to the next, at least one of the factors must be on the decline. Slowing the growth of some or all factors can help mitigate impacts, but growth of one or more factors must be reversed to actually decrease impacts. It stands to reason that Technology, structured as impact per activity (often Impact/GDP or Impact/Energy), has been the prime candidate for reversal [7]. Behavioral and cultural aspects of society can be largely ignored and the task assigned to engineers whose job it has always been to reduce resource use – and by extension "impact" – per unit of useful work [5, 14].

But the difficulty technology has, and will continue to have, in combating both population and affluence/activity rise is demonstrated in Figure 7.2. Here, data from the International Energy Agency (IEA) and World Bank are used to chart world energy use (in Terajoules, TJ) during the period 1990–2014 [15, 16]. The components of world energy use mirror those of the IPAT equation. Final energy is the product of Population, Affluence (Gross World Product (USD)

[1] At some point, increasing material affluence (as quantity of goods or speed of services) fails to deliver increasing well-being [7], a point made by many advocates of degrowth [8, 9]. Thus, "affluence" is not necessarily a marker of happiness, welfare, well-being, or prosperity.

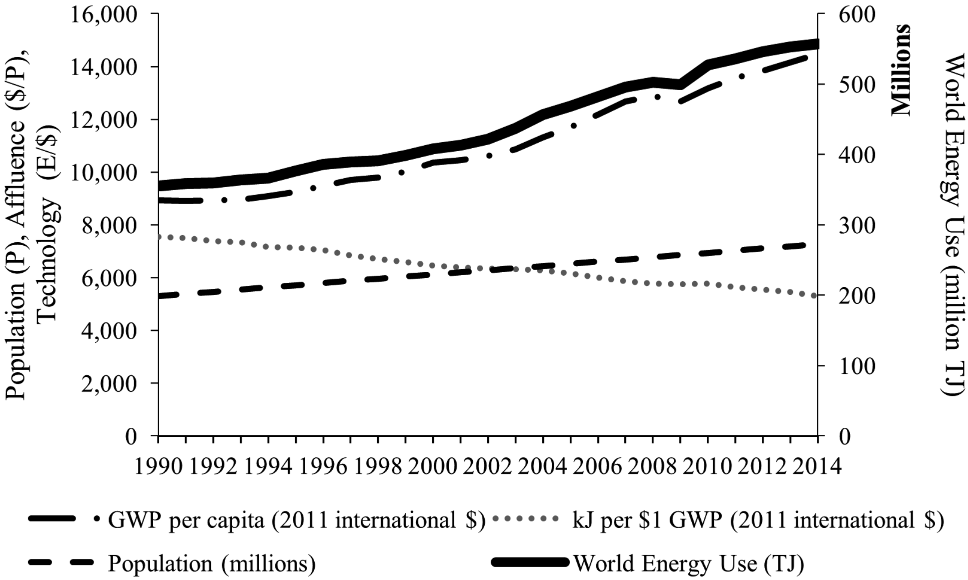

Figure 7.2 World Energy Use, 1990–2014, composed of Population, Affluence, and Technology parameters

per capita), and Technology (energy required per unit GWP). Energy use and per capita wealth have risen in a synchronized manner, with the only major dip in energy use occurring in conjunction with economic downturn in 2009 [17, 18]. Technology, framed here as the energy intensity of the economy (kJ/GWP), has indeed improved in efficiency, but has been unable to keep pace with economic and population growth.

7.2.2 Positive Feedbacks and the Rebound Effect

Observing technology, as defined in the classic IPAT equation, and focusing solely on impact per unit of activity, the achievements of sustainable technology and engineering are impressive. Some achievements that have particularly benefited technological interventions in developing country settings are described in Table 7.1.

With the analytical borders drawn solely around a single technological parameter – as in Table 7.1 – it is possible to ignore important ways that technological progress feeds back (positively or negatively) to population and affluence. This can lead to what are called "rebound effects," in which the savings from reduced pollution, resource inputs, or production effort are invested in the growth of production activities [26]. This is sometimes referred to as a "paradox," but is, in fact, a natural consequence of most energy engineering efforts in

Table 7.1 *Modern technology and associated efficiency metrics*

Technology	Metric	Efficiency improvement	Source
Light-emitting diode (LED) lighting	Lumens per watt (lm/W)	A typical household lamp light draws 9W with LED technology, compared to 60W for its equivalent-light incandescent predecessor	[19]
Photovoltaic electricity generation	Solar energy input per electricity output (%)	Module efficiencies reached 40% in 2019, compared to a maximum of 20% in 1990	[20]
Insect-resistant (IR) crops	Yield (Harvested mass per area planted)	From 1996 to 2015, IR traits are credited with global yield increases of 13% for maize and 15% for cotton	[21]
Precision irrigation	Water uptake per water applied (%)	Drip irrigation systems equipped with soil moisture sensors improve efficiency by 3–19%	[22]
Additive manufacturing	Energy per product	Small-scale 3D printers can reduce energy inputs by 41–64%	[23]
Information processing	Transistors per integrated circuit (# per die)	Computing capability per circuit has improved exponentially, from 100 in 1970 to 10^{11} in 2017	[24]
Batteries	Energy density (kWh per kg)	Improved from 150 to 300 kWh/kg between 2010 and 2020	[25]

the modern age [27, 28]. For example, improving the efficiency of cars reduces the gasoline and greenhouse gas (GHG) emissions consumed and emitted per distance driven, but overall, there is an absolute increase in gasoline consumed and GHG emissions from driving due to this rebound effect. Rebound is not only a characteristic of consumer choices, it manifests just as fundamentally in the engine of capital itself, where money saved through improvements in material efficiencies are reinvested into production, which ultimately grows production and its attendant impacts more in absolute terms, even when relative gains to efficiency are achieved [29].

Innovators and researchers claiming environmental benefits from technological or infrastructural change are increasingly being called to address the potential for rebound effects in their evaluations [30, 31]. Zink and Geyer [32] recently criticized the popular "circular economy" movement for largely ignoring rebound effects as a potential outcome of manufacturing efficiency efforts. They point out, for example, that the current market for refurbished cell phones, rather than contributing to reduced new production, has grown up alongside increased cell phone production. Their study claims that "the smartphone circular economy (how it is currently practiced) necessarily leads to rebound." They conclude that "rebound could be a serious obstacle to creating meaningful environmental improvement."

By focusing our eyes on the efficiencies of new gadgetry, eco-technological concepts, like renewable energy and the circular economy, may distract us from confronting norms of consumption that underlie and facilitate the persistence of environmental violence on a global scale [33]. If we are lulled into accepting ever-expanding purchases of technology-forward goods and services, we will never pull back the green curtain hiding the realities of our one, global, and interconnected economy [34]. Keeping the affluence–technology in our vision is, thus, critical for developing appropriate and effective approaches to sustainability.

7.2.3 The Affluence–Technology Connection

The affluence–technology connection is complex. No single methodology can capture the bi-directional mechanisms by which current affluence and the evolving demands of society influence technological design, and technological design influences consumption activity and evolving demands and desires. Sociological research in sustainability has been especially clear about the fact that environmental outcomes are not unidirectional. They cannot be viewed as simply the outcome of aggregated individual decisions (bottom-up), nor the collective response to economic and technical structures (top-down). According to Shove et al. [35], environmental outcomes at the global or societal scale can be seen as the result of "practices," hybrid structures that evolve from the interplay of individual decision-makers, social norms, and available technology.

Shove and colleagues also point to the need for lower-consumption practices to develop, in order to achieve truly sustainable ways of living. Through a review of energy efficiency rebound in building technologies, Shove [36] concludes that perhaps the most robust definition of sustainable technologies would be those that "do not meet present needs, and do not deliver equivalent levels of service, but that do enable and sustain much lower-carbon ways of life." Once planners and engineers treat this as a viable option, she argues, an entirely new scope of design for true sustainability will open up. One way to characterize this scope is what growth critic Tim Jackson has called "prosperity without growth" [37]. Meanwhile, low-carbon and prosperous lifestyles are already being enjoyed in many parts of the world, cultivated through social and technological traditions oriented away from growth and toward prosperity [38, 39].

7.3 Appropriate Technology

The industrial–capitalist–technological system is characterized by perpetual growth through excessive production, relentless marketing and public relations to expand markets and demand through consumerism [40, 41]. In the process, novel "needs" are manufactured and the boundaries and norms of comfort and convenience are continually reshaped [42, 43]. In this system, relatively few technologies are socially necessary, and their manufacture and multiplication are exacerbating ecological destruction and global social injustice. Because it is organized around the maximization of profit, this system foments an ever-accelerating throughput of matter-energy and output of waste [44]. Technological planned obsolescence begets material objects of short functional lifespan, but nearly permanent environmental harm, being made of industrial processes and novel chemicals that do not return safely to the environment (e.g., plastics, stain-proof coatings, heavy metals). Perceived obsolescence, driven by the same forces that manufacture demand for novel products, is equally responsible for overconsumption and its attendant environmental harms. While it is true that smart phones, for example, have offered unprecedented levels of interconnectivity and access to information, and many would now consider them indispensable, the only reason to sell more phones than there are users is profit. The "style cycle," where companies change product design (often in a cyclical manner), continues to lend the appearance of novelty to its products so that consumers feel pressured to keep up to date with the latest technology. The cycle is further propelled by the resource and positional inequities; turnover is maintained through a constant struggle for "more" among consumers seeking to better their perceived position in society [45, 46].

From an equity and sustainability perspective, the reigning technological system is fundamentally inappropriate. Despite wearing the mantle of high-positivist and rationalist science, it bears all the characteristics of a giant Rube Goldberg machine, where solutions, no matter how brilliant in isolation, are applied to either ridiculous ends or a ridiculous complication of means. Each stage of the unnecessary or absurd contraption itself produces a new series of problems requiring further (profitable) technical mitigation, treatment, and externalization in turn. A modern life cycle assessment can be almost endlessly applied to most modern complicated technologies (i.e., those that are mechanized and motorized, powered by fossil fuels or electricity) and the globalized, capitalist economic system in which they circulate. Technologies under this system, being commodities, are created and organized for the purpose of generating surplus exchange value for profits, rather than use or subsistence value for needs. As Otto Ullrich points out, the vastness of this lifecycle entails an insidious seductiveness, since it disperses, mystifies, and socializes its real costs in time and space, causing a "non-intersection between advantages that are privately consumable and disadvantages that have to be borne collectively" [47]. Those disadvantages of high technology within capitalist globalization today include exploitation, "slow violence" [48], and pollution on a planetary scale, costs which are socially paid, but nevertheless, hidden from the end consumer. As K. William Kapp famously remarked, "Capitalism must be regarded as an economy of unpaid costs" [49].

Fledgling efforts at true cost accounting to incorporate externalities into prices have floundered against the regime of capitalist globalization of the past few decades, where systematic worldwide cost-shifting is the sine qua non of multinational corporations' profitability and growth. Only by way of this accounting sleight of hand can complicated high-tech devices appear "efficient" against simple manual tools. This is to the benefit of both producer and consumer, who externalize costs of environmental impacts to often-distant ecosystems and peoples they rarely have to see or think about. The consumer is, by design, naïve, which is to the advantage of the producer, who better understands the impact of their business, but manufactures and protects the blissful ignorance of the consumer to promote a narrative of ethical and sustainable consumption.

Companies could be forced to internalize these costs through regulatory means, or production could be decommodified and optimized to reduce impacts throughout the supply chain. Yet, there remain challenges, disagreements and biases around how or whether to assign monetary value to externalized costs, and economic decisions are usually better made by considering the material impacts of production and consumption, as well as first asking what the appropriate goods and services are to live well within the means of the planet, rather than through a circuitous monetized proxy and fraught attempts at cost internalization [50].

7.3.1 Principles of Appropriate Technology

Contrarily, "traditional" (defined here as land-based, peasant) cultures have been marked by "subsistence technologies" that embody a radically opposite set of values and design principles that together constitute a template for the "original appropriate technology" (AT), which finds many parallels – with modifications – in the contemporary AT movement.

These principles include, inter alia: use value over exchange value; social necessity; place-based, hand-made and low- or no-energy; non-polluting; durable, but also, ultimately safely biodegradable; democratic and decentralized; and

Table 7.2 *Ten principles of AT*

1	Socially necessary; not frivolous or from marketing manipulation (artificial need); no technology where none needed
2	Place-based, locally sourced natural materials & local knowledge
3	Hand-made
4	Non-polluting (either locally/directly or distantly/indirectly), non-toxic, safe
5	Durable functional use; easily locally repairable and recyclable; constituent materials safely and completely biodegradable
6	Simplest, least complicated design for functional use
7	Operating at slow speeds (or no speed)
8	Low-energy and direct use of passive (wind, water, sun) or simple active energy (biomass, muscle power)
9	Democratic – decentralized; built, used, maintained, repaired locally; common knowledge vs. proprietary; promotes social equality, discourages hierarchy
10	Non-alienating (from our own labor, ourselves, each other, and nature), non-livelihood-destroying

non-alienating (Table 7.2). Perhaps most importantly, consonant with the insights of social critics ranging from William Morris to Gandhi to Ivan Illich, is the avoidance of technical interventions and superfluous innovations where none are needed, or where their utility may be overwhelmed by their harms: the sufficiency principle and the precautionary principle, respectively. These suggest a broader "a-novation" principle – the application of intelligence and creativity to not-doing, to non-production. As William Morris insisted, "nothing should be made by man's labour that is not worth making, or which must be made by labour degrading to the makers" [51]. Related to this, in traditional cultures, social relations of cooperation, reciprocal labor and care often substitute for individualized and privatized technical means. In Ladakh, India, for example, villagers traditionally pool their labor to harvest and process everyone's crops in a staggered fashion, engage in communal shepherding of livestock on a rotational basis, and distribute gravity-fed irrigation water equitably using simple spades and soil under ingenious networks of hand-dug canals and turn-taking. These forms of cooperative labor largely obviate the need for technologies in the first instance or facilitate the practicality of local AT.

7.3.2 Two Types of Appropriate Technology

Traditional/original AT, based on communal social arrangements, hand-crafted from local, natural materials that cultures have used for centuries mostly for subsistence purposes, not only points toward environmental sustainability, but, by minimizing or eliminating dispersed costs, is also structurally non-violent. One can think, for example, of the traditional water mill still in common use in villages throughout many mountainous agrarian regions: constructed of local, natural materials based on ancestral knowledge; communally owned, utilized, and repaired; running on non-polluting gravity-fed water; pollution and waste free; operating at relatively slow speeds and low temperatures; and so on. No downstream community is harmed or poisoned by the construction or operation of these water mills.

What we call modern AT (aka Intermediate Technology) comprises tools and machines that may use materials from the industrial economy (thus, occasioning some indirect pollution), but otherwise shares many characteristics with traditional AT, especially economic independence, political democracy, and social cohesion.

Suffice it to say that many modern ATs have been eagerly adopted by traditional cultures, because such technologies graft well onto and enhance the subsistence economy, while responding to novel challenges of modernity, and maintaining critical qualities like autonomy and cooperation, even if some of them necessitate entanglement with the cash economy. For example, in Ladakh, such modern ATs as solar cookers and water heaters, rocket stoves, ram pumps, trombe walls, and other passive solar building techniques are widespread. This belies misperceptions of traditional cultures as static and closed; indeed, traditional ATs themselves are the result of centuries of careful refinement and innovation [52]. Still, the chief disadvantage of both traditional AT and modern AT vis-à-vis modern high technology is precisely in their non-mystifying nature: less privatized convenience borne of cost-shifting. This lack of "convenience," conventionally conceived, and the physical muscle input required in its use, have been the very features of traditional technology long denigrated as backward, and a pretext for colonial intervention and domination [53, 54]. This domination continues, as both traditional and modern ATs are being quickly displaced by industrial products and materials, and traditional cultures are eroded by incorporation into the extractive global economy. This is of particular concern at a time when living examples of AT and sustainable modes of social organization are so desperately needed to navigate the downscaling of industrial society. A major challenge is saving and reviving them before they disappear, for, as Illich once remarked, the great advantage of a place like rural Guatemala or India is "still being muscle-powered enough to stop short of an energy stroke" of the sort suffered by the over-developed societies [55].

The modern AT movement, intermeshed with the degrowth movement, is pursuing exactly this sort of "reverse development," a sort of re-peasantization and deliberate inconveniencing, motivated both by ethical objections to the structural violence of high technology, and by practical ones of independence and autonomy especially from centralized energy grids and fossil fuel oligarchies. Some outstanding examples include: L'Atelier Paysan, a French cooperative that works with farmers to design machines and buildings appropriate to the unique needs of small-scale agroecology, in the pursuit of "technological sovereignty" [56]; Maya Pedal in Guatemala, a social enterprise building pedal-powered non-electric bicycle machines for numerous practical household and small farm applications; and Can Decreix, a center for putting degrowth principles into practice, based on low- or no-tech living in France, among many others.

Beyond tools, movements working to rebuild community and decommodify life through projects of sharing and repairing are also pointing the way toward a "social AT": repair cafes, remakeries, tool-lending libraries, and reskilling hubs [57]. Movements politically resisting corporate practices of "planned obsolescence" and the criminalization of repair are also important elements of the broader AT shift [58], as are those focused, not on ever more innovation, but rather, "exnovation" to dismantle harmful technologies and technological systems that are incompatible with eco-socially just futures [59].

7.3.3 Following Original Appropriate Technology

There is no AT in traditional cultures independent of traditional community-based social arrangements: reciprocal or differential labor sharing and care, mutual aid, and the like. The two are mutually constitutive. Just as sustainability cannot be achieved merely by adding renewable electricity technologies to an otherwise unchanged consumerist-industrial growth economy, neither can AT in isolation make significant impact situated within an otherwise congenitally unsustainable system. Part of the essence of AT emerges from, in, and for community life. Unsustainable substitutions are often ushered in in the wake of community disintegration, and cause further such disintegration in turn, because, by nature, they obviate the community element and privatize the use and shift allegiance/dependence to global industrial supply chains. AT is, therefore, not just a matter of tools and artifacts, but requires supportive social and political-economic conditions. For AT to thrive will require transcendence of capitalism-industrialism and the structural drivers such as massive subsidies and the global advertising industry that expand its power, and a return toward smaller-scale, more localized, non-violent sufficiency economies. AT, in turn, will be necessary to enable such economies.

As the dominant techno-industrial system drives the planet over the precipice of ecological catastrophe, and deepens social maladies of alienation (from our own labor, ourselves, other people, and nature) and injustice, the need to downscale, decentralize, and de-grow the economy becomes ever more apparent and urgent.

The "original AT" of traditional cultures and its contemporary applications and modifications offer important contributions to this pressing task of subordinating the economy and its technologies to social and ecological survival.

7.4 Affluence-Limiting Technology in the Global North: The Case of Transportation and Speed

Transportation is a sector that has continually expanded its geographic, cultural, and technological reach and where differences among economies are stark. Per capita transportation distances are clearly tied to the size of the overall economy, rising in correlation with per capita GDP [60]. In the United States, this rise has continued somewhat linearly through the turn of the century, while in emerging economies such as India, it has grown exponentially [60, 61]. Here too, feedback from technology to affluence cannot be ignored. The evolution of fuel economy in US motor vehicles, charted in Figure 7.3, displays a coordination between technological efficiency, fuel use, and distance traveled, which mirrors the trend shown earlier for energy use.

Transportation, after all, is demand for an energy service. Humans don't demand energy directly – they demand the capabilities that available energy can provide to them. In transportation, this capability is the movement of mass (people and their things) over a distance, in a constrained period of time. In the context of the IPAT equation then, we can frame several technological parameters related to transportation.

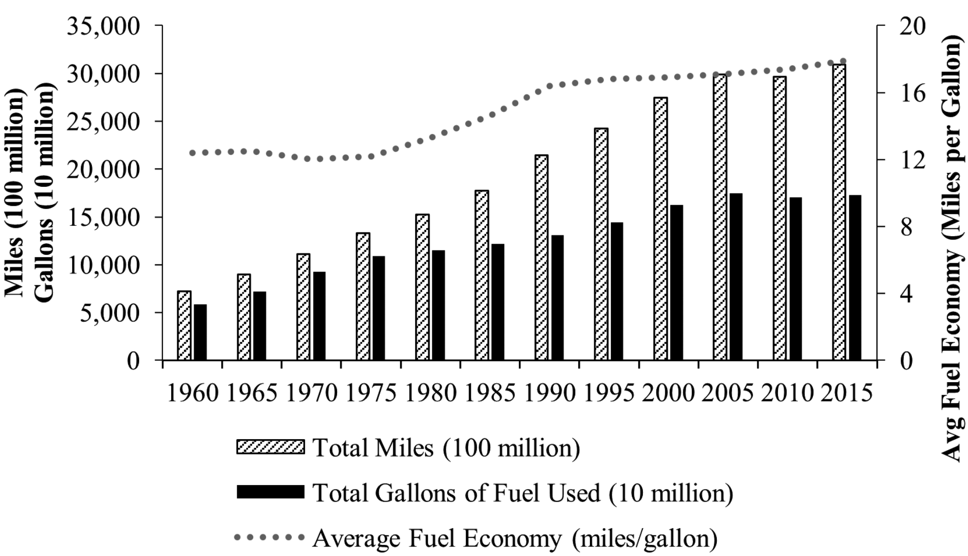

Figure 7.3 US Vehicle Travel, Fuel Use, and Fuel Economy, 1960–2015

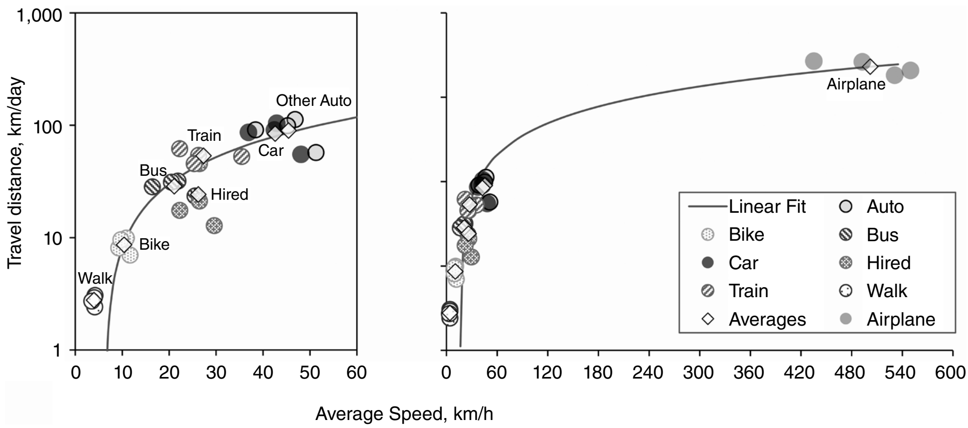

Figure 7.4 Average travel distance and speed by mode [62]

As we consider what it will take to achieve carbon emissions reduction goals, we must consider, not only the impact-per-unit requirement (i.e., carbon intensity) of transportation, but also potential changes in the quality of modes of transportation used. Speed is a key factor that changes the nature of the technology used. Looking at transportation survey data from the United States for the period 1990 to 2017, it can be seen that the average speed of transportation is very consistent when daily travel activity is grouped by mode (Bus, Train, Car, etc., Figure 7.4). This means that "speeding up" or "slowing down" transportation as a whole is not a matter of regulating travel speeds within a given mode, rather, it is a matter of mode-switching. In turn, each mode has a different carbon intensity owing to its material and mechanical differences.

Taking these standards into account then, what range of transportation affluence (demand) and technologies (vehicle types and speeds) would be capable of meeting ambitious targets for reducing carbon emissions in the US transportation sector? Consider the affluence–technology "solution space" for achieving emissions reductions that fulfill the US commitment embodied in the Paris Climate Accord, that is, to lower emissions to 70% of 2017 levels. This area is conceptualized in Figure 7.5: on the *x*-axis is average travel speed for the entire population, calculated based on mode share and the mode-speeds described above, and on the *y*-axis is average travel activity per person per year (in kilometers). Thus, each point on the graph represents an average affluence–technology (as distance-speed) scenario for the US transportation sector.

Furthermore, at each coordinate, we can calculate the total sector emissions in 2030, across the population and including all modes of transportation. Applying different assumptions about technology development and travel habits yields

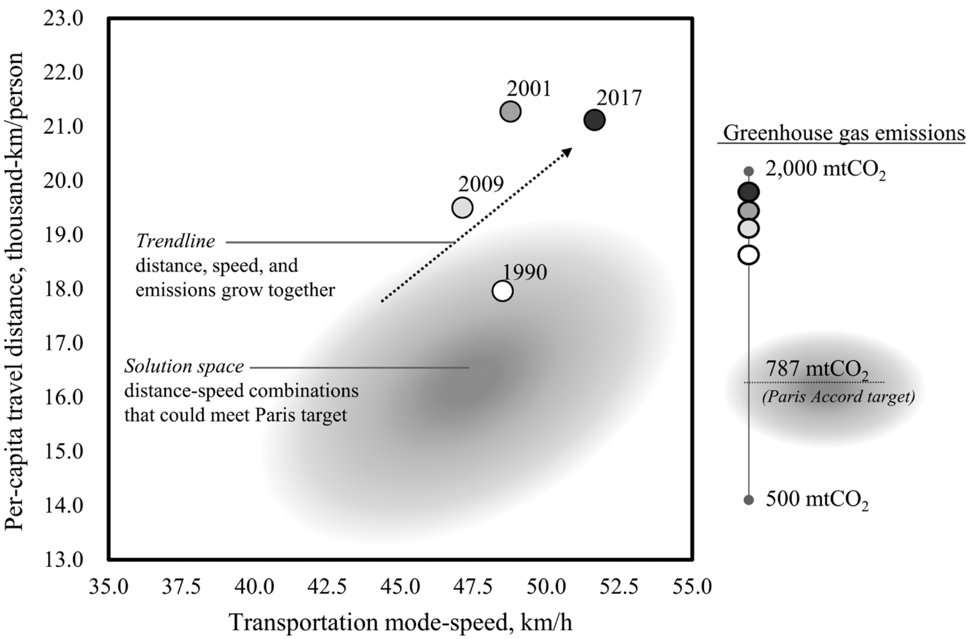

Figure 7.5 Climate action solution space, 2030 historical speed-distance (x–y) levels depicted for US, based on NHTS survey data

different "solution spaces." The space depicted uses the following reasonable assumptions for sustainably and equitably achieving our Paris commitment:

Ambitious decarbonization via efficiency: the carbon intensities (gCO_2/km) of car, airplane, and transit fleets decrease to 70% of 2017 levels (the average efficiency improvement rate over the past two decades)

Increasing adoption of walk, bike, and transit modes: public transit use increases by 40% (as transportation becomes more urban and shared) and walking/biking activity increases by 50% (a key goal for sustainability advocates)

These results communicate just how little space is available to increase transportation activity and speed, while still meeting ambitious environmental goals. Transportation levels for previous survey years are given, showing that, even if Americans were to travel at distances and speeds similar to those recorded in 1990, the transportation sector would barely achieve Paris Accord goals. Furthermore, even though some goal-achieving scenarios exist at higher speeds (to the right of the heatmap), they still require a reduction in per capita travel distance.

It may sound simplistic to claim that lowering environmental impact requires a slowing of technology and a lowering of economic activity, but here we have found, through deliberate quantitative analysis, that this is most likely to be the case.[2] And because transportation lies at the heart of so many aspects of our modern economy, it is not a stretch to claim this as a general lesson. It is a tough lesson, especially because we are so accustomed to techno-optimism – hoping for technology alone to bring about change, without disturbing our climb to ever-greater levels of affluence.[3]

7.5 Sector-Based Solutions Do Not Obviate the Need for Appropriate Affluence

Next, we communicate the findings of a recent study by Horen-Greenford and colleagues entitled, "Shifting economic activity to services has limited potential to reduce global environmental impacts due to the household consumption of labor" [65]. This study has both policy implications and important lessons for the concepts of appropriate technology, levels of affluence and consumption, and appropriate notions of development. In our study, we demonstrate from a fresh perspective that the consumption levels of affluent people will likely need to decrease, even when employing more people in services. Our findings further discredit the promise of environmental "decoupling" and "green growth" – colloquially understood as the ability to grow the economy without environmental damage.

Traditionally, environmental decoupling[4] refers to the practice of disconnecting environmental impacts (i.e., resource use or pollution) from economic activity. For example, one may say that energy production is decoupling from GHG emissions as coal power is taken offline and replaced with renewable energy. To be more precise, if global GHG emissions rise more slowly than gross world product, but still continue to rise, "relative decoupling" is occurring (i.e., there has been a partial disconnection of impacts from activity). If GHG emissions plateau or decrease as gross world product increases, "absolute decoupling" is occurring (i.e., there has been a complete disconnection of impacts from activity). Absolute decoupling is needed for green growth, since exponential increases in economic activity will still cause exponentially increasing impacts [66]. Mounting evidence suggests that technological innovation cannot be relied on to ensure the environmental sustainability of continued economic growth since environmental impacts are part and parcel of economic activity and there is little evidence for believing rates of decoupling can increase enough to allow

[2] Others have found this to be true more generally, after careful appraisal of possible scenarios. Keyser and Lenzen [63] show that only degrowth scenarios can meet climate targets with feasible levels of technological innovation. Otherwise, unrealistic levels of decoupling would be needed.

[3] Anderson [64] writes specifically on the influence of techno-optimism on high-level global climate planning and negotiations.

[4] Or "economy–environment decoupling," to be more precise.

for envisioned economic growth [67, 68]. Realizing this, a growing number of scientists and economists are highlighting the need to rein in the consumption of the global affluent [69].

Our study adds to these insights by formalizing an alternative definition of decoupling that has become prominent in sustainable development discourse. Instead of pursuing environmental decoupling through technological improvements, like efficiency gains or energy transitioning, many believe that structural changes to the economy (i.e., how the economy is composed) could yield lower impacts, while still allowing us to grow the economy. An economy that is heavily implicated in extraction is called a primary economy. The typical depiction of economic development begins with basic subsistence like agriculture, and on extracting raw materials for export, then an economy uses its increasing wealth to build up industry, thereby transitioning to a secondary economy, which is more reliant on heavy industry like manufacturing industrial (e.g., steel, textiles, semiconductors) and consumer goods (e.g., automobiles, clothing, electronic devices). Excluding their imperial and colonial legacies, this describes how rich countries envision industrialization.[5] Finally comes the promise of a clean environment with a powerful economy, made possible by a final transition to value-dense services that are ostensibly largely immaterial. This is the last stop on the path of western economic development, referred to as "tertiarization," or a shift to a more services-oriented economy.

This narrative is so familiar that it's taken for granted by many in economics and international development, as well as the private and public spheres. The promise of a high-tech clean future is featured prominently in the future envisioned by Silicon Valley entrepreneurs and captains of the green corporate world. Advocates of environmental and social justice within civil society see well-paying jobs in public services and green infrastructure as an integral part of a transition to a more equitable and ecological society.[6] Everyday people in the Global North have heard

[5] Some countries that have gained wealth through so-called (conventional) development, like Canada and Australia, never really graduated from primary economics of resource extraction and rip-and-ship, and still export an abundance of raw materials without adding value to them. It's not uncommon for these countries to be former colonies of European empires, which retain their economic models despite their newfound independence. These habits die hard, and the political influence of these incumbent industries makes economic development very difficult. In many ways, the governments of Canada and Australia serve the interests of extractive industry much more than any other interest group. While wealthy extracting nations do provide many public services and a high standard of living for many of their citizens, their main efforts are directed at facilitating the development of frontier extraction, with little fundamentally changing since these countries were formed out of colonial outposts.

[6] It is worth noting that the future envisioned by proponents of a Just Transition is far more tenable than that proposed by Silicon Valley and green capital, with their emphasis on work and economic sectors vital to transitioning away from fossil fuels toward more sustainable forms of energy, and other sectors central to human well-being like healthcare and education. The two narratives differ here but hold in common a reluctance to speak directly of limits to affluence and consumption. One may presume with confidence that this is because such ideas are seen as politically untenable.

these stories increasingly over recent decades, as more people are desperate for solutions to our ecological and climate predicaments. The sustainable development goals (SDG) presuppose green growth via a shift to a service economy, which is central to the SDGs "decent work for all" (SDG 8) and achieving "responsible consumption and production" (SDG 12).

This theory had been previously formalized as the Environmental Kuznets Curve (EKC), which proposed that environmental impacts followed an inverted U-shape, increasing with industrialization, but plateauing and decreasing after a certain level of affluence was obtained [70]. The reasoning was analogous to the trajectory of inequality versus wealth of a nation, as originally observed by economist Simon Kuznets, that at first, a nation could not afford to be environmentally conscious (or equitable, in the original theory), but after it reached a certain level of wealth, people preferred a cleaner environment to marginal increases in wealth. Unfortunately, this wasn't the whole story. It was true that wealthier people prefer to live in a cleaner environment, but their pollution did not disappear – much of it moved (and continues to be exported) to poorer countries along with heavy industries. Capital found cheaper labor and laxer environmental protection in the Global South, while developed countries enjoyed higher wages in service-rich economies, and the cleaner environment that came with a post-industrial society. When we look at trade flows, and account for the resources and pollution linked to consumption, most impacts have continued to increase proportionally to consumption. The empirical basis for the EKC hypothesis has now been largely disproven [68], but the idea lives on, inhabiting a host of ideas in economic development literature and policy, and in the public mind.

To answer the question of whether services are cleaner than ostensibly dirtier sectors, like food production or heavy industry, we knew that it would be necessary to consider the impacts of household consumption by those employed in these industries. It seemed suspicious that we could have a clean and lucrative economy by simply employing more people in well-paying jobs, be they public (e.g., healthcare, public administration, education) or private (e.g., software, insurance, consulting), since people employed in these services are well off and have very consumptive lifestyles, relative to most people on the planet. Naturally, we expected that if you considered what people ultimately spend their income on, and if you were to grow the economy by increasing the relative share of high-wage jobs in the services sector, you would also increase consumption and its attendant impacts.[7]

[7] All else being equal, of course: For the purpose of our thought experiment, we necessarily assume that there are no substantial changes to technology or people's behavior in the short term. We also assume that structural changes to the economy are relatively small and incremental. If you were to change a substantial portion of the economy very quickly, then the impacts of sectors would also change, and would need to be

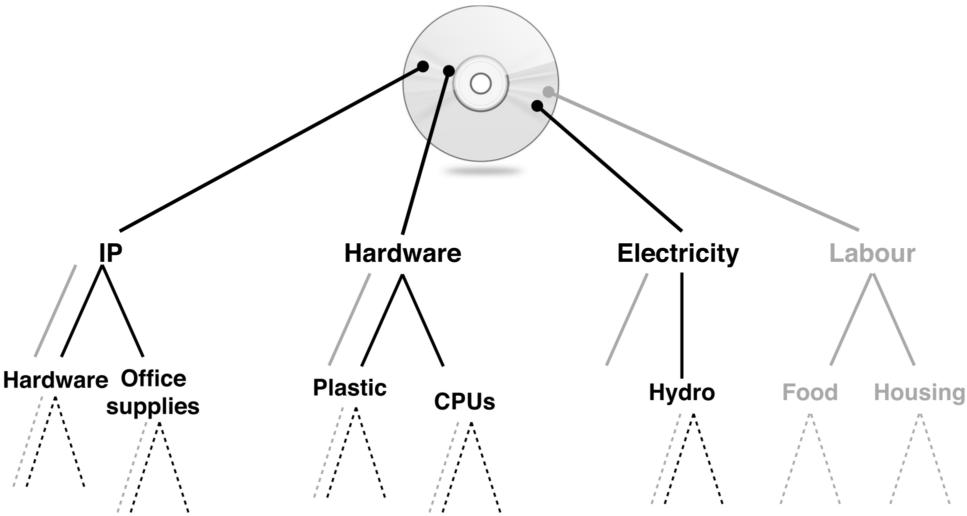

Figure 7.6 Schematic of methodology: including (endogenizing) labor as part of economic production. Blue inputs indicate examples of labor and household consumption attributed to an industry

To show what would happen to environmental impacts because of increases in personal consumption following a shift to services, we attributed the impacts from household consumption of employed people to the industries that employed them. This effectively endogenizes labor as part of production. We then used input–output economics to estimate the total environmental impacts related to industrial activity when considering all the inputs that go into every industry. This approach is known as environmental "footprinting" or "consumption-based accounting," and traces production all the way down the supply chain, without double counting inputs or impacts. See Figure 7.6 for a visual representation of our method. Figure 7.7 depicts our results where, in absolute terms, the impacts of services doubled for GHG emissions, and tripled for land use and water consumption, respectively, while GHG emissions and land use for food production were each reduced by seven times, and water consumption by a factor of 10. The profound shift observed was expected and intuitive, but astonishing in its degree.

However, we still needed to answer the fundamental question: Are services cleaner, per unit value created, than their "dirtier" counterparts? Only then could we attempt to answer the larger question of whether a transition to a more services-oriented economy actually holds the key to green growth.

modeled dynamically. Our model provides a static snapshot of the global economy as it is, and adequately serves our purpose of answering the question: What would happen to environmental impacts if you made an incremental change to any given sector of the global economy?

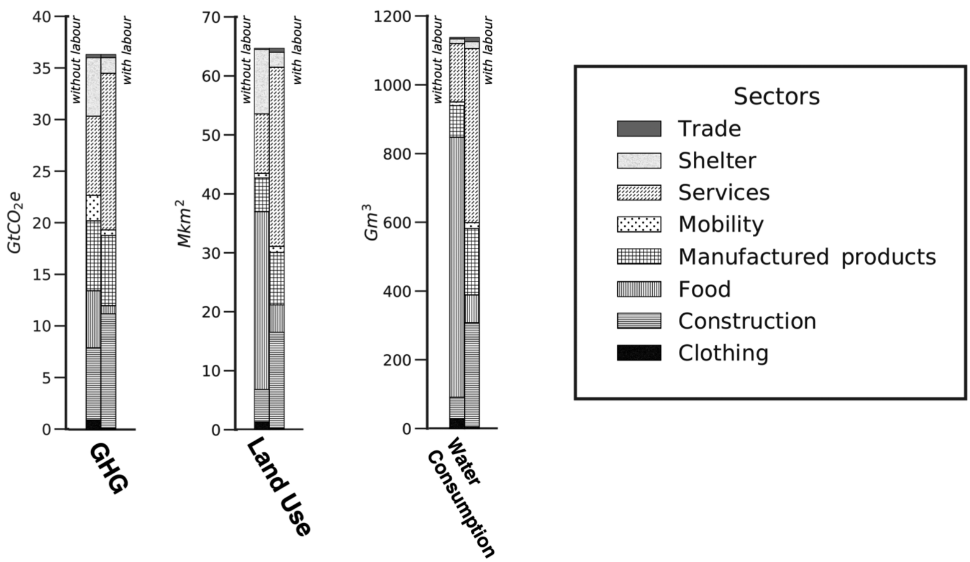

Figure 7.7 Results: Global impacts by sector, before and after inclusion of labor in supply chain

Figure 7.8 depicts our secondary results: The distributions of impacts per unit value before and after household consumption of employed people is included in industrial impacts. Notice how, in the conventional picture, that is, before including household consumption, services seem to give a much better "bang for your buck," with much lower impacts per euro than food, which has much higher impacts per euro made, being relatively less value dense. The story fundamentally changes after adopting a more holistic perspective. Impacts of all economic sectors converge, there being no statistical difference in impact between producing a euro of food or a euro of services.[8] Now we can account for the cascading effects of employing more people in services. We can also now begin to derive some conclusions about whether the promise of tertiarization or, more specifically, a high-tech green future, is plausible. This is where we necessarily must diverge from the data and model at hand, to some more speculative, but hopefully, well-grounded, postulates.

Given the mounting evidence that green growth via technological innovation is unlikely and caution or good judgment implores us to not rely on a fantastic miracle to save us,[9] it seems that sustainable growth is untenable by any strategy,

[8] It is important to note that there is one minor exception, where water consumption is still statistically higher for Food than Shelter but, barring this, there are no statistically significant distinctions between these sectors. However, this choice of industry classification is not the only one available, and other schemes yield different results, and are still in line with our hypothesis. For a more comprehensive discussion of sensitivity to industry classification and sectoral aggregation, see our paper and its supplementary information [65].

[9] Or, more strongly, that technological innovation will always be insufficient to offset growth because of fundamental physical limits and mathematical rules.

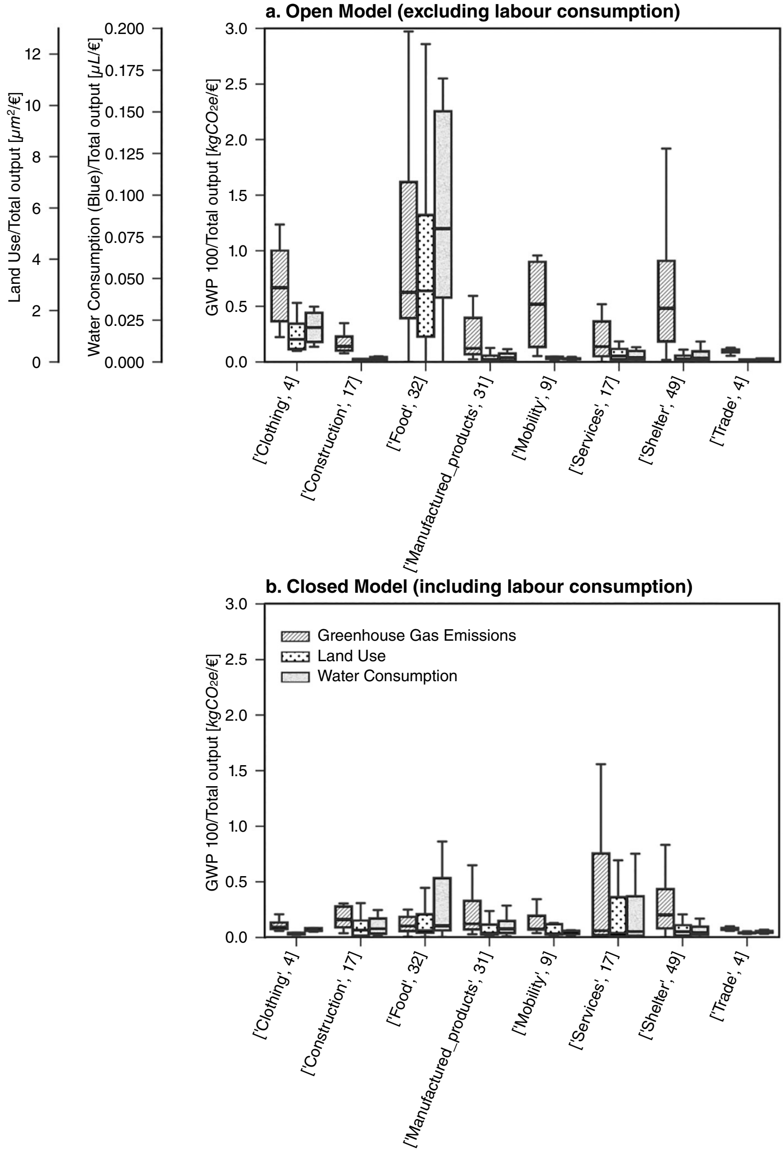

Figure 7.8 Results: Sectoral impact per unit value, before and after inclusion of labor in supply chain

but there is not a lack of options. There are roads less recently traveled, but just as open to us, if we choose to follow them – ones that lead to more appropriate levels of affluence and consumption. Given the previous evidence and our recent study's findings, we've concluded that there is no way around constraining economic size, and that if we are to achieve the heart of the SDGs, of better lives for more people, especially those living in destitute poverty now, there will need to be a wide scale redistribution of wealth and resources. Finding the appropriate lifestyles and technologies for different regions and people should be our challenge. Whatever we (the global affluent) choose – living well with less, regardless of where we work or how wealthy we are – must be part of an environmentally sustainable and just world.

7.6 Degrowth Futures: Appropriate Affluence and Technology

Technological progress is not an autonomous process. It is constantly being reinterpreted and revaluated by the societies that interact with technology. Writing about our global environmental conundrum, researchers [71] assert that "visions of the future are key elements in the process of technological development and acceptance." In other words, human aspirations can play a key role in directing the kind of technologies that are pursued and which ultimately prevail. Society is generally aware of the global environmental effects of human activity and yet we are still running a technological advancement program very much like the one that prevailed over a century ago. Reimagining technology in a lower-affluence framework, could be a key step in pursuing true global sustainability. This concept of appropriate affluence forms the overarching theme that ties degrowth and appropriate technology together.

The affluence–technology connection is the link that has, so far, prevented AT efforts from breaking through the global trend of increasing pollution and ecological destruction. In this section, we have simply detailed the mechanics of the affluence–technology connection in order to prove that it must be confronted within any robust sustainability framework. The degrowth framework most directly confronts issues of affluence, making it AT's natural partner for an appropriate and sustainable future. While AT thrives in many parts of the world, it is not yet driving appropriate degrowth where it matters most – among the global affluent. In this article we have mentioned some promising initiatives, such as re-peasantization, repair cafés, and tool-lending libraries. Such efforts will grow as a necessary condition of socially just degrowth, but they will not gain traction until structural and cultural space is made for them. Degrowth's focus on decolonizing the imaginary of what constitutes a "sustainable future" is a key connection point with the environmental violence framework [72].

Degrowth also adds a global and systemic perspective on technological progress that is essential for reimagining technological "progress." After all, are the Wright brothers to blame for the globe-spanning impacts of the airline industry today? They started out as tinkerers of simple means in a Main Street bike shop (Figure 7.9). Their genius created a functional airplane, and the global economy took over from there. A degrowth + AT framework asks for regulations and constraints on the size of the global economy, while embracing and emphasizing human ingenuity at the community scale.

Figure 7.9 Wright Brothers Bike Shop, circa 1900 [73]

References

[1] McCullough D. *The Wright Brothers*. Reprint edition. Simon & Schuster; 2016. 336 p.

[2] Rhodes R. *Energy: A Human History*. 1st edition. New York: Simon & Schuster; 2018. 480 p.

[3] Wright O. 1903 Wright Flyer engine section. 1928.

[4] NASA on The Commons. Wright Glider, Kitty Hawk [Internet]. 1903 [cited Mar 22, 2023]. Available from: https://commons.wikimedia.org/wiki/File:The_Wright_Brothers%27_First_Heavier-than-air_Flight_(7605918566).jpg

[5] Smil V. *Energy and Civilization: A History*. Cambridge, MA: The MIT Press; 2017. 552 p.

[6] Rockström J, Steffen WL, Noone K, Persson A, Chapin III FS, Lambin E et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society.* 2009;14(2): 32.

[7] Jess A. What might be the energy demand and energy mix to reconcile the world's pursuit of welfare and happiness with the necessity to preserve the integrity of the biosphere? *Energy Policy.* Aug 2010;38(8): 4663–78.

[8] Assadourian E, Starke L, Mastny L. Worldwatch Institute. *State of the World, 2010: Transforming Cultures: From Consumerism to Sustainability*. A Worldwatch Institute report on progress toward a sustainable society. New York, NY: W.W. Norton; 2010.

[9] Daly H. A further critique of growth economics. *Ecological Economics.* Apr 2013;88: 20–4.

[10] Ehrlich PR, Holdren JP. Impact of population growth. *Science.* 1971;171(3977): 1212–7.
[11] York R, Rosa EA, Dietz T. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*. Oct 2003;46(3): 351–65.
[12] Chertow MR. Industrial symbiosis: Literature and taxonomy. *Annual Review of Energy and the Environment.* 2000;25: 313–37.
[13] World Bank. World development indicators [Internet]. 2018 [cited Jan 24, 2019]. Available from: https://datacatalog.worldbank.org/dataset/gdp-ranking
[14] Mumford L. *Technics and Civilization* [Internet]. New York: Harcourt, Brace and Company; 1934 [cited Jan 24, 2019]. Available from: www.press.uchicago.edu/ucp/books/book/chicago/T/bo10388066.html
[15] IEA – International Energy Agency [Internet]. IEA. [cited Mar 22, 2023]. Available from: www.iea.org/data-and-statistics
[16] World Bank Open Data | Data [Internet]. [cited Mar 22, 2023]. Available from: https://data.worldbank.org/
[17] Beaudreau BC. Engineering and economic growth. *Structural Change and Economic Dynamics*. Jun 1, 2005;16(2): 211–20.
[18] Hall CAS, Klitgaard K. *Energy and the Wealth of Nations: An Introduction to Biophysical Economics*. 2nd edition. Cham: Springer; 2018. 511 p.
[19] US EPA (United States Environmental Protection Agency). *The Light Bulb Revolution*. Washington, DC: Office of Air and Radiation, Climate Protection Partnerships Division; 2017 p. 13.
[20] NREL (National Renewable Energy Laboratory). Champion module efficiencies [Internet]. National Renewable Energy Laboratory; [cited Jan 24, 2019]. Available from: www.nrel.gov/pv/assets/pdfs/research-module-efficiency-chart.20190115.pdf
[21] Brookes G, Barfoot P. Environmental impacts of genetically modified (GM) crop use 1996–2015: Impacts on pesticide use and carbon emissions. *GM Crops Food*. Apr 3, 2017;8(2): 117–47.
[22] Soulis KX, Elmaloglou S, Dercas N. Investigating the effects of soil moisture sensors positioning and accuracy on soil moisture based drip irrigation scheduling systems. *Agricultural Water Management.* Jan 31, 2015;148: 258–68.
[23] Kreiger M, Pearce JM. Environmental life cycle analysis of distributed three-dimensional printing and conventional manufacturing of polymer products. *ACS Sustainable Chemistry & Engineering*. Dec 2, 2013;1(12): 1511–9.
[24] Gargini PA. How to successfully overcome inflection points, or long live Moore's law. *Computing in Science Engineering.* Mar 2017;19(2): 51–62.
[25] BloombergNEF: Lithium-Ion Battery cell densities have almost tripled since 2010 [Internet]. [cited Jul 4, 2020]. Available from: https://cleantechnica.com/2020/02/19/bloombergnef-lithium-ion-battery-cell-densities-have-almost-tripled-since-2010/
[26] Gillingham K, Rapson D, Wagner G. The rebound effect and energy efficiency policy. *Review of Environmental Economics and Policy.* Jan 2016;10(1): 68–88.
[27] Jevons S. *The Coal Question*. London: Macmillan; 1866.
[28] Odum HT, Odum E. *A Prosperous Way Down*. Boulder: University Press of Colorado; 2001.
[29] Bliss S. Jevons paradox [Internet]. Uneven Earth. 2020 [cited Dec 1, 2022]. Available from: https://unevenearth.org/2020/06/jevons-paradox/
[30] Chang JJ, Wang WN, Shieh JY. Environmental rebounds/backfires: Macroeconomic implications for the promotion of environmentally-friendly products. *Journal of Environmental Economics and Management.* Mar 2018;88: 35–68.
[31] Magee CL. A taxonomy for technology models used in environmental impact studies. *Procedia CIRP.* 2018;69: 412–6.

[32] Zink T, Geyer R. Circular economy rebound: Circular economy rebound. *Journal of Industrial Ecology*. Jun 2017;21(3): 593–602.
[33] Marcantonio R, Fuentes A. Environmental violence: A tool for planetary health research. 2021.
[34] Kingston E. Shopping with a conscience? The epistemic case for relinquishment over conscientious consumption. *Business Ethics Quarterly*. Apr 2021;31(2): 242–74.
[35] Shove E, Spurling N, Shove E. *Sustainable Practices: Social Theory and Climate Change* [Internet]. London, UNITED KINGDOM: Routledge; 2013 [cited Nov 11, 2019]. Available from: http://ebookcentral.proquest.com/lib/uic/detail.action?docID=1157759
[36] Shove E. What is wrong with energy efficiency? *Building Research & Information.* Oct 3, 2018;46(7): 779–89.
[37] Jackson T, Daly H, McKibben B, Robinson M, Sukhdev P. *Prosperity Without Growth: Economics for a Finite Planet*. 1st edition. London; Washington, DC: Earthscan Publications Ltd.; 2011. 286 p.
[38] Hickel J. Is it possible to achieve a good life for all within planetary boundaries? *Third World Quarterly*. Jan 2, 2019;40(1): 18–35.
[39] O'Neill DW, Fanning AL, Lamb WF, Steinberger JK. A good life for all within planetary boundaries. *Nature Sustainability*. Feb 2018;1(2): 88–95.
[40] Ewen S. *Captains of Consciousness: Advertising and the Social Roots of the Consumer Culture, 25th Anniversary Edition*. 25th edition. New York, NY: Basic Books; 2001. 272 p.
[41] Kasser T, Kanner AD, editors. *Psychology and Consumer Culture: The Struggle for a Good Life in a Materialistic World*. Washington, DC: American Psychological Association; 2004. xi, 297 p. (Psychology and consumer culture: The struggle for a good life in a materialistic world).
[42] Illich I. *Toward a History of Needs*. New York: Pantheon Books; 1978.
[43] Shove E. *Comfort, Cleanliness and Convenience: The Social Organization of Normality*. Oxford: Berg; 2003. 221 p. (New technologies/new cultures).
[44] Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, et al. Planetary boundaries: Guiding human development on a changing planet. *Science*. Feb 13, 2015;347(6223): 1259855.
[45] Ordabayeva N, Chandon P. Getting ahead of the Joneses: When equality increases conspicuous consumption among Bottom-Tier consumers. *Journal of Consumer Research*. Jun 1, 2011;38(1): 27–41.
[46] Veblen T. *The Theory of the Leisure Class: An Economic Study of Institutions*. Stuttgart: B. W. Huebsch; 1899. 422 p.
[47] Ullrich O. Technology. In: Sachs W, editor. *The Development Dictionary: A Guide to Knowledge as Power*. London: Zed Book; 1992. 308–322 pp.
[48] Nixon R. *Slow Violence and the Environmentalism of the Poor*: Cambridge, MA: Harvard University Press; 2013. 368 p.
[49] Kapp KW. *Social Costs of Private Enterprise*. New York: Schocken; 1971.
[50] Victor PA. Cents and nonsense: A critical appraisal of the monetary valuation of nature. *Ecosystem Services*. Apr 1, 2020;42: 101076.
[51] Morris W. *The Collected Works of William Morris: With Introductions by His Daughter May Morris*. Cambridge, UK: Cambridge University Press; 2012.
[52] Watson J. *Lo-TEK: Design by Radical Indigenism*. Cologne: Taschen; 2019.
[53] Adas M. *Machines as the Measure of Men: Science, Technology and Ideologies of Western Dominance*. Ithaca and London: Cornell University Press; 1989.
[54] Adas M. *Dominance by Design: Technological Imperatives and America's Civilizing Mission*. Cambridge, MA: The Belknap Press of Harvard University Press; 2006.
[55] Illich I. *Energy and Equity*. London: Calder and Boyars; 1974.

[56] Bauwens M. Julien Reynier and Fabrice Clerc from L'Atelier Paysan on self-build communities in farming. Commons Transition. Mar 17, 2017.
[57] Bradley K, Persson O. Community repair in the circular economy – Fixing more than stuff. *Local Environment.* Nov 2, 2022;27(10–11): 1321–37.
[58] PIRG. Right to Repair [Internet]. PIRG. 2022 [cited Dec 16, 2022]. Available from: https://pirg.org/campaigns/right-to-repair/
[59] Kruger T, Pellicer-Sifres V. From innovations to exnovations. Conflicts, De-Politicization processes, and power relations are key in analysing the ecological crisis. *The European Journal of Social Science Research.* 2020;33(2): 115–23.
[60] Schafer A, Victor DG. The future mobility of the world population. *Transportation Research Part A: Policy and Practice.* Apr 2000;34(3): 171–205.
[61] Singh SK. The demand for road-based passenger mobility in India: 1950–2030 and relevance for developing and developed countries. *European Journal of Transport and Infrastructure Research* [Internet]. Jun 1, 2006 [cited Jul 14, 2020];6(3). Available from: https://ojs-lib2.tudelft.nl/ejtir/article/view/3448
[62] US DOT (Department of Transportation). National household travel survey data [Internet]. Downloads. 2018 [cited Apr 23, 2019]. Available from: https://nhts.ornl.gov/downloads
[63] Keyßer LT, Lenzen M. 1.5°C degrowth scenarios suggest the need for new mitigation pathways. *Nature Communications.* May 11, 2021;12(1): 2676.
[64] Anderson K. Duality in climate science. *Nature Geoscience.* Dec 2015;8(12): 898–900.
[65] Greenford DH, Crownshaw T, Lesk C, Stadler K, Matthews HD. Shifting economic activity to services has limited potential to reduce global environmental impacts due to the household consumption of labour. *Environmental Research Letters.* Jun 16, 2020;15(6): 064019.
[66] Ward JD, Sutton PC, Werner AD, Costanza R, Mohr SH, Simmons CT. Is decoupling GDP growth from environmental impact possible? *PLOS ONE.* Oct 14, 2016;11(10): e0164733.
[67] Hickel J, Kallis G. Is green growth possible? *New Political Economy.* Jun 6, 2020;25(4): 469–86.
[68] Haberl H, Wiedenhofer D, Virág D, Kalt G, Plank B, Brockway P, et al. A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: Synthesizing the insights. *Environmental Research Letters.* Jun 2020;15(6): 065003.
[69] Wiedmann T, Lenzen M, Keyßer LT, Steinberger JK. Scientists' warning on affluence. *Nature Communications.* Jun 19, 2020;11(1): 3107.
[70] Kaika D, Zervas E. The Environmental Kuznets Curve (EKC) theory – Part A: Concept, causes and the CO_2 emissions case. *Energy Policy.* 2013;62(C): 1392–402.
[71] Sovacool BK, Brown MA, Valentine SV. *Fact and Fiction in Global Energy Policy: Fifteen Contentious Questions*. Baltimore: Johns Hopkins University Press; 2016. 370 p.
[72] Kallis G, March H. Imaginaries of hope: The utopianism of degrowth. *Annals of the Association of American Geographers.* Mar 4, 2015;105(2): 360–8.
[73] NASA on The Commons. Wright Brothers Bicycle Shop [Internet]. 1937 [cited Mar 22, 2023]. Available from: www.flickr.com/photos/nasacommons/16590683660/