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Green Machines?
Destabilizing Discourse in Technology Education for Sustainable Development

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Abstract

Technology education (TE) and education for sustainable development (ESD) increasingly converge. This makes perfect sense given the techno-optimism that permeates the prevailing discourse on sustainable development. The present article reviews mainstream and more critical work within this emerging literature. A central argument is that even the more critical studies in the field tend to feed into the techno-optimistic sustainable development discourse; as they do not contest conventional understandings of technology, the scope of their critique remains limited. Reiterating Hornborg's theories of machine fetishism and ecologically unequal exchange, the present paper offers a radically different outlook and ultimately two conclusions are drawn. First, rather than engaging in conversations with fellow proponents of technological solutions, scholars in this emerging field ought to spend more time responding to those who seriously question technology's ability to deliver environmental and social sustainability. Second, if technology educators are sincere about wanting to promote technical literacy more broadly, the eco-innovation curriculum must be supplemented with perspectives that interrogate the prospects for a 'green' modernity.

Introduction

A literature that merges technology education (TE) and education for sustainable development (ESD) has been growing over the past years. This is hardly surprising as the prevailing discourse on sustainable development is imbued with faith in the possibility of technological solutions to our environmental predicaments. While works in this emerging field, broadly referred to here as *technology education for sustainable development*, all share a concern with the debris of industrial modernity they do not represent a single or unified approach. The field has not yet reached the level of maturity that is typically associated with consolidated theoretical positions, but there are discernable differences in terms of how the prospects for eco-innovation are contextualized and discussed, ranging from mainstream to more critical views. However, as will argued in this article, even the more critical studies in the field appear to adhere to rather conventional understandings of what technology is and what it can do for the planet. This limits the scope of their critique and arguably most of the critical works actually feed into the techno-optimism of the sustainable development discourse.

It should be recognized that the concept of discourse is contested and that it has been instilled with different meanings for different purposes (e.g. Bacchi, 2000). Yet, at the most basic level, most discourse theorists would probably agree that discourse broadly refers to an assemblage of statements, representations and truth-claims that somehow shape and delimit people's perception and conception of the world (e.g. Howarth & Torfing 2005; Jørgensen & Phillips, 2002). Hence discourse enables *and* restricts what is possible to perceive, think and do. In other words we can contend with Dodge & Silverberg (2015) that discourse *matters*. Conversely, it is widely agreed amongst discourse theorists that problematizing what is taken for granted and making the invisible visible, are important strategies for destabilizing and challenging discourse. The present paper is an attempt in this vein. The article reviews mainstream and more critical literature in the emerging field of technology education for sustainable development. Furthermore, in contrast to these studies, the paper attempts to offer an alternative outlook. A central argument is that the curriculum should supplement dominant narratives about 'green' machines with technology critique. More specifically what needs to be challenged in ESD is our very conception of 'technology'. Such a perspective, borrowed from political ecology, could hopefully enrich the field and provide an impetus for productive discussions amongst scholars, teachers and students.

The article's overall concern with issues of power, inequality and discourse can be related to previous work in what can broadly be referred to as *critical studies of ESD* (e.g. Dahlbeck, 2013; Hellberg & Knutsson, 2016; Ideland & Malmberg, 2014; Knutsson, 2013; McKenzie, Bieler & McNeil, 2015; Sjögren, Gyberg & Henriksson, 2015; see also Pedersen, 2010ab). Yet, in terms of the present paper's specific engagement with the *concept* of technology in relation to ESD, new terrain is explored. It should of course be recognized that prominent and critical environmental educationalist like, for example, Chet Bowers (e.g. 2011, 2015) has engaged at length with the commonplace and undue faith that technology can reverse the destruction of natural systems. However, as indicated above, the contribution of this paper lies in the didactic argument that the curriculum needs to be supplemented with an alternative conceptualization of what technology 'is'. Arguably, and here I partly draw on personal experiences as a university teacher, such a conceptual move is the most efficient way of turning the techno-optimism of sustainable development on its head.

The article is structured as follows. The first section contextualises the paper's arguments by providing a brief recapitulation of how the environmental discourse has transformed over the past decades. The second section reviews mainstream and more critical

literature in the emerging field of technology education for sustainable development. Drawing on political ecology, the third section offers a radically different outlook on technology and environmental concerns that challenge existing work within the field, as well as the prevailing sustainable development discourse. The concluding section discusses the implications of the article's arguments in relation to both scholarly debate and the curriculum of technology education for sustainable development.

Sustainable Development: From the 'Limits to Growth' to the Wonders of Technology

Over the past decades we have witnessed a significant reconfiguration of the environmental discourse. Using broad brush strokes, this transformation can be sketched as follows. In the 1970s and early 1980s it was commonplace amongst both scholars and environmentalists to perceive the relationship between modern development and environmental protection as a contradiction (e.g. van der Heijden, 1999; Mol & Spaargaren, 2000). The dominant schools of thought in environmental social science at the time were deindustrialization theory and neo-Marxism. In a similar vein the struggle of the green social movement in these years was intimately connected to a critique of the industrial capitalist system and the economic growth model as such (ibid.). Given its major impact on public debate – sold in 30 million copies and translated into 30 languages – the seminal report *The Limits to Growth* from 1972 serves as a rather useful example of this historical stance (Meadows et al., 1972). The report, written by a number of researchers at Massachusetts Institute of Technology (MIT) on behalf of the Club of Rome, contended that the earth's limited resource base and capacity to absorb waste inevitably sets limits for economic growth. Moreover, despite being authored by scholars from the MIT, the report engaged in a lengthy dismissal of the argument that technology could somehow decouple economic growth from negative environmental impact:

> We have felt it necessary to dwell so long on an analysis of technology here because we have found that *technological optimism is the most common and the most dangerous reaction to our findings* from the world model. Technology can relieve the symptoms of a problem without affecting the underlying causes. *Faith in technology as the ultimate solution to all problems can thus divert our attention from the most fundamental problem – the problem of growth in a finite system* and prevent us from taking effective action to solve it (Meadows et al., 1972, p. 154, *my emphasis*).

However, the report also became subject to an immense critique. Particularly from neoliberal economists who argued that the authors severely underestimated human ingenuity and the dynamics of the economy. These critics suggested that the market mechanism would catalyze substitution of scarce resources by creating incentives for entrepreneurs to invest in new technological solutions. The report was also widely accused of conveying a groundless eschatological rhetoric.[1] In the wake of this critique and the broader ideological reconfiguration of the 1980s, the environmental discourse underwent something of a metamorphosis. In this process the perception on the relationship between environmental concern and promotion of modern development was effectively reversed. This new language is clearly manifested in the widely influential *Our Common Future*, also known as the Brundtland report:

[1] However, historical analysis of the debate has shown that it is rather these portraits of the report as a doomsday prophecy that are ungrounded (Nørgård, Peet and Ragnarsdóttir, 2010).

> Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits – not absolute limits but limits imposed by *the present state of technology* and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But *technology* and social organization *can be both managed and improved to make way for a new era of economic growth* (WCED, 1987, p. 8, *my emphasis*).

Hence, in the emerging sustainable development discourse of the late 1980s the problem definition, as well as the conception of the relationship between economic growth and environmental degradation, was reformulated. Economic growth was no longer seen as a problem but rather as a part of the solution. The basic idea being that economic growth is necessary to finance new 'green' technology and to cover future expenses for cleaning up old environmental damage. As indicated in the quote above the sustainable development discourse also includes high hopes in technology's ability to bend environmental limits and minimize pollution. In this respect sustainable development basically reflects the vision of a 'green' modernity. Scholars certainly played their part in this discursive transformation and proponents of ecological modernization theory have since long contended that they won the battle against the growth critics and techno-pessimists of the 1970s (Mol & Spaargaren, 2000; see also Hajer, 1995). That the once so critical voice of the environmental movement has been largely replaced by more 'pragmatic' and technocratic approaches in the wake of its increasing dependence on and complicity with state, market and multilateral institutions, is also something that has been widely recognized by eco-modernists (e.g. Mol, 2000) and more critical scholars (e.g. van der Heijden, 1999; Blühdorn, 2013) alike.[2]

Of significant importance in this context is also that governments around the world — as part of broader policies on sustainable development – have committed to implement ESD at all levels of their educational systems as manifested in the *United Nations Decade of Education for Sustainable Development (2005–2014)* (United Nations, 2002) and the subsequent *Global Action Programme on Education for Sustainable Development* (GAP) (United Nations, 2014). Hence, education is now officially recognized as an important companion in the generic and worldwide quest for sustainable development. Some might of course argue that initiatives like the Decade and GAP boil down to nothing more than empty rhetoric but that is not the point here. Rather, the point is that demonstrating commitment to (education for) sustainable development is uncontroversial, as this enterprise does not really challenge the status quo of the political economy. Arguably, it rather helps *sustaining* it (Hellberg & Knutsson, 2016).

By way of summary, the environmental discourse has undergone a fundamental transformation in the direction of eco-modernization and growing faith in 'green' technological solutions. Moreover, education has become increasingly recognized as a key strategy for realizing the vision of sustainable development. Given these two developments the emerging nexus between technology education and ESD makes perfect sense. This brings us to the next section of the paper.

[2] The concept of *post-politics* has been used in critical studies of sustainable development (e.g. Swyngedouw, 2007) and critical studies of ESD (Knutsson, 2013) to capture this tendency towards depoliticisation and technocratic government.

The Technology Education–ESD Nexus: Mainstream and Critical Studies

The technology education–ESD nexus is manifested in a growing number of articles, books, conference panels and university courses around the world. Throughout this paper this body of scholarly work is labelled as *technology education for sustainable development*. As the field is still young theoretical positions are yet to be consolidated. However, there are noticeable differences as to how the prospects of technology in relation to sustainable development are contextualized and discussed, ranging from mainstream to more critical views. Without claiming to be comprehensive, but indicative of the general discourse, this section first provides examples of mainstream studies and then engages with more critical works in the domain.

Mainstream studies are broadly concerned with how technology education, be it in schools or in engineering programmes at university level, can be improved and geared towards sustainable development. Common denominators are: explicit concern with the environmental challenges that the world is facing; faith in the prospects of 'green' technological solutions to such problems; and belief in the importance of (technology) education as a means to foster the necessary capabilities to develop and master such 'green' innovations. Hence, these studies tend to position themselves against 'out-dated' modes of technology education (or industrial modernity wit large) in favour of approaches that seeks to marry environmental sustainability with technological progress. Some of these studies provide inventories of existing curricula to determine improvement needs (e.g. Lundquist & Svanström, 2008; Segalàs et al., 2009). Literature reviews (e.g. Desha, Hargroves & Smith, 2009), historical recapitulations (e.g. Mulder, Segalàs & Ferrer-Ballas, 2012) and large-scale surveys (e.g. Azapagic, Perdan & Shallcross, 2005) have also been conducted to identify challenges and possible avenues of improvement. Many studies also provide positive examples ('best practice') of how introducing new pedagogical content and methods have enhanced technology students' learning for sustainable development, as well as technology teachers' abilities to facilitate such learning (Biswas, 2012; Eilks, 2015; Filho, Manolas & Pace, 2009; Glassey & Haile, 2012; Svanström et al., 2012). These studies must be seen as solid academic work. However, they clearly operate within the parameters of a discourse that this paper sets out to destabilize. As these studies basically share the techno-optimistic underpinnings of 'sustainable development' certain things become (im)possible to perceive, think and do.

There are, however, also studies that display a more critical attitude. In a series of contentious articles – with explicit titles such as *Transcending the Age of Stupid* and *Overcoming the General Motors Syndrome* – Leo Elshof has highlighted the shortcomings of technology education in relation to sustainable development *and* argued for more critical approaches (Elshof, 2009, 2010, 2011, 2015). A recurrent message in his work is that technology education has largely been subsumed to the demands of the industrial capitalist system. Moreover, when sustainability issues are raised, they are typically reduced to technical matters of eco-innovation: superficial 'tinkering practices' and tacit hopes that environmental problems can somehow be subject to 'techno-fix' (Elshof, 2009, p. 135). Elshof demands more from technology education as he argues that it must recognize the 'deeper problematic political, ecological and power dynamics that characterize our economies and our technological lifestyles' (ibid.). In other words, technology education cannot be blind to issues of economic and environmental (in)justice. Elshof further recognizes that there are 'ecological limits that no amount of technological ingenuity may

ever resolve' (ibid., p. 137) and that technological critique ought to be given a prominent role in the curriculum.

Given this, it is a bit surprising that each of his papers still concludes with explicit hopes in technological innovation. For example he contends: that ''new path' technological solutions remains our best hope for a sustainable future' (Elshof, 2009, p. 143) and that technology education must provide 'new narratives of how technology might help us to create and sustain a new world worth living in' (Elshof, 2011, p. 160). That growth in the global 'green collar economy' is repeatedly used as an argument for promoting skills for eco-innovation (Elshof, 2009, 2010, 2011, 2015) is also something that raises questions.[3] To be fair, Elshof recognizes the urgent need of systemic change and the importance of technology critique. Yet, a lasting impression is that conventional conceptions of 'technology' are never really challenged. Nor is the full measure of how technological development and global inequality interlace problematized. Hence, arguably, the reason why Elshof ends up placing hope in (socially just) technological innovation is that he subscribes to a rather conventional understanding of what technology 'is' and what it can do for the planet. As will be argued below this hampers his otherwise important critique.

Critical work has also been conducted by Margarita Pavlova (2009, 2011, 2013). Claiming that we need to move beyond industrialization and radically democratize the global economy (Pavlova, 2013, p. 735) she has made calls for a critical and transformative technology education. Pavlova argues that technology education for sustainable development must go beyond a one-dimensional focus on eco-design to discuss the underlying causes of environmental problems. Hence technology education discourse has to be broadened to incorporate social, political and international dimensions, as well as critical thinking. She also stresses that responding to the planetary crisis requires that we 'change our worldviews' (ibid.) and that technology education has an important role to play in this endeavour.

Pavlova has also been pioneering in bringing in discussions about the so-called 'developed' and 'developing' countries in relation to technology education for sustainable development (Pavlova, 2011, 2013). She contends that 'the first group needs to reduce their per capita ecological footprint without impairing their quality of life, the second one needs to improve the well-being of their citizens without drastically increasing their ecological footprints' (Pavlova, 2013, p. 737). She also argues that these challenges must be reflected in technology education policies that are appropriate to different country contexts. Now, as will be evident in the next section, the idea that technology can be geared to maintain the quality of life of rich people while at the same time securing global equity and environmental protection is up for debate. Moreover, some concerns can be raised in relation to Pavlova's discussion about how technology education should respond to different challenges in rich and poor countries. While contextualization is certainly important there lies a potential danger in focusing on singular country contexts and assorted 'appropriate' technological solutions. Such a focus runs the risk of disregarding *relations* between different geographical areas in the world system. Hence, while recognizing the importance of Pavlova's work, the prospects for the new 'ethics' that she proposes, and for the socially just technological solutions 'that serves the best interest of all parties involved' (ibid., p. 741), can be seriously debated.

Finally, I will bring attention to two significant, albeit somewhat older, critical contributions by Petrina (2000a) and Petrina and O'Riley (2001). Stephen Petrina (2000a) has severely criticized conventional methods in technology education, suggesting that they are

[3] Elshof (2011, p. 159) further contends: 'The countries that make the most rapid transition to a low carbon way of business will be the economic leaders of tomorrow', a statement that can be challenged on both empirical and normative grounds.

profoundly unsustainable. He makes a case for remodelling technology education on the basis of political ecology. Such an approach, Petrina argues, involves paying close attention to ecological footprints, resource streams and wakes. Moreover, to seriously contemplate the significance of such biophysical information for how technology education is practiced. Petrina's work is exceptional in that it offers little faith in technological solutions to the world's environmental problems. 'No amount of eco-design is going to add up to sustainability' (ibid, p. 229) he claims. Instead 'the issue is that western cultures are overproducing and over-consuming at the rest of the world's and the future's expense' (ibid. p. 212). Ultimately, Petrina contends that a political ecology informed approach to technology education means nothing less than to work for a fundamental transformation of western lifestyles *and* reduced production and consumption. As will be evident below, Petrina's view is, in many respects, close to the arguments of the present paper. Arguably, however, a limitation in Petrina's (2001a) article is that he never offers any lucid conceptualization of what technology 'is'.[4] How environmental injustice and modern technological development interlace therefore remains somewhat unclear. As will be evident in the next section, I believe that reconceptualising technology is key to understanding this problem. Hence, while sharing Petrina's general outlook, I still maintain that a *re*turn to political ecology can be helpful to further the critique.

Stephen Petrina and Patricia O'Riley (2001) have offered another important piece of the puzzle by bringing attention to matters of political economy. Their paper draws on Schumacher's (1973) seminal study *Small is Beautiful: Economics as if People Mattered,* more specifically his work on intermediary technology, later popularized as appropriate technology (AT). Petrina and O'Riley provide an overview of the economics of AT, showing how its decentralized, labour-intensive, collective, and environmentally sound application constitutes a radical alternative to the global market economy and to conventional development thinking. Petrina and O'Riley further situate technology education in the context of political economy, thus recognizing that the economic organisation of social life sets preconditions for technology. For Petrina and O'Riley the pedagogical implications are clear: 'Teaching AT in design and technology education necessarily requires that economic matters be addressed without bowing to the compulsions and dictates of capitalism' (Petrina & O'Riley, p. 42). If technology education really wants to make a difference in terms of environmental protections it cannot, they argue, be taught as if capitalism was the only game in town. It simply must consider the possibility of an alternative economy. As will be shown below Petrina and O'Riley's perspective is, once again, close to the view of the present paper. Still, their arguments for local currencies in economies of AT can be further developed by considering some of the perverse effects of general-purpose money. Moreover, a simple juxtaposition of the logics of general-purpose money with some basic physical conditions set out by the second law of thermo-dynamics can further add to Petrina and O'Riley's arguments. Again, this calls for a *re*turn to political ecology.

By way of summary, critical representatives of technology education for sustainable development emphasize the importance of changing our worldview. Arguably, however, if technology education really is to become such an eye opener it has to challenge common sense conceptions of what technology 'is' and critically consider the conditions that actually makes it possible. As will be shown below such a discursive move forces us to seriously reconsider conventional wisdom about technological solutions for sustainable development.

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[4] With reference to the new sociology Petrina only states that 'technology is socially constructed through differentials of capital and power' (Petrina, 2001a, p. 211). While I believe that this statement is correct I doubt that the meaning is transparent to a wider audience.

The Green Machine as a Pipe Dream: Lessons From Political Ecology

So, where might those concerned with technology education for sustainable development turn for an alternative outlook? The academic tradition known as political ecology is preoccupied with how asymmetric power relations and environmental destruction interlace, i.e. how economic and technological 'development' in wealthy areas of the world occur at the expense of the environment and health of people in poor areas (for overviews see e.g. Clark & Jorgensen, 2009; Hornborg, McNeil & Martinez-Alier, 2007; Paulson & Dezon, 2005). As shown above, Petrina (2000a) has also stressed the significance of a political ecology perspective in relation to technology education. Here, however, I will draw on Alf Hornborg (e.g. 2001ab, 2006, 2009, 2011) and his theories of *machine fetishism* and *ecologically unequal exchange.* The section is not attempting to provide a comprehensive or in-depth account of Hornborg's enormous scholarly production. Readers interested in learning more are kindly directed to his original works. Rather, this is an attempt to foreground certain aspects of Hornborg's work that I believe serves well to challenge, supplement and enrich current discussions in the field of technology education for sustainable development.

An illuminative theory of global environmental injustice must, Hornborg argues, incorporate a theory of technology. Hornborg is of course not the first to engage critically with how technology and domination entwine. There is a rich critical tradition in the philosophy of technology and critique of technology certainly also appear in the domain of technology education.[5] The importance of Hornborg's contribution, however, must be understood in the context of contemporary discourse on sustainable development. As will be evident below Hornborg effectively turns the commonplace idea of technological solutions to our environmental predicaments on its head by bringing close attention to the uneven flows of matter and energy upon which machines ultimately hinges.

In Hornborg's view, conventional conceptions of technology are misleading. Notably we are talking about *modern* technology that requires expert knowledge, division of labour, infrastructure and non-organic energy use, i.e. not simple artifacts that could be built by single households solely based on materials from their immediate environment. Most of us tend to think about technology as something that saves labour and physical resources, i.e. that technology somehow transcends limitations in time and space. Little surprise, then, that virtually all political camps are placing huge hopes in technological innovation or, as indicated above, that the prevailing discourse on sustainable development is imbued with the same faith. However, to attribute autonomous productivity to technology, or to believe that it can bend environmental limits, is essentially to ascribe to it magical properties; it is to mystify global unequal relations of exchange. Hornborg uses the concept of *machine fetishism* to capture these widespread cultural illusions (e.g. Hornborg, 2001ab, 2011).[6] His point is that we, in our everyday encounters with machines, tend to disregard the enormous and unequal flows of matter and energy that brought them to existence and that keeps them running. Hence machine fetishism basically reflects the commonplace imagination that

[5] For example, Petrina (2017) has recently published an intellectual history of technology critique. For a recent edited volume on critical approaches to technology education see also Williams and Stables (2017). It should also be mentioned that Hornborg, quite naturally, positions his own work vis-à-vis previous technology critique (see e.g. chapter 1 in Hornborg 2001b).

[6] Hornborg thus extends the Marxist notion of fetish from money and commodities to technology, arguing that the preeminent fetish of industrial capitalism – i.e. the machine – has actually escaped Marxist analysis (e.g. Hornborg 2001a).

(uneven) exchange relations are irrelevant to how machines work, i.e. that a group's technological capacity (be it 'green' or not) is independent of that group's position in a global system of resource flows. A related common misconception is our tendency to take unequal distribution of modern technology across geographical space as a reflection of different developmental stages in historical time. In other words: the false assumption that eventually, when poor areas around the world have 'caught up', we will all be enjoying the comforts of modern technology (Hornborg, 2009, 2011).

According to Hornborg it is more adequate to conceptualize technology as an 'institution for redistributing time and space' (Hornborg, 2001a, p. 489). Hence, contrary to conventional wisdom, technology does not really save much. Rather, it makes it possible for those who are in possession of modern technology to gain time and space at the expense of people and environment in other parts of the globe, i.e. it is a means for time-space appropriation. Modern technology is essentially premised upon a global zero sum game of uneven resource flows and environmental load displacement. Technological development in core areas is ultimately dependent on a continuous net inflow of biophysical resources from the peripheries. This is also, Hornborg stresses, a self-reinforcing process. The ecologically unequal exchange yields further technological advancement in rich areas, which rewards them with even more biophysical resources to consume, thus further increasing the asymmetries. Of note here is that ecologically unequal exchange, for Hornborg, refers to asymmetric transfers of matter and energy, measured in biophysical metrics, i.e. *not* underpayment in terms of economic 'value'.[7] Furthermore, environmental load displacement enables people in wealthy areas to enjoy a high level of technological consumption without having to witness any immediate negative impact in their local environments. Environmental destruction is basically 'outsourced' to poor areas (e.g. Hornborg, 2006, 2009, 2011).

What, then, makes machines and the asymmetric flows of matter and energy that they are inexorably associated with, possible? According to Hornborg it is ultimately global differences in the price of labour and natural resources, morally legitimized by economic theory and political ideology claiming that market prices by definition are fair and based on reciprocity. These, in fact, *unequal* exchange relations make it possible for those with purchasing power to continuously accumulate resources, technology and money, at the expense of others, in a self-reinforcing spiral. This helps explain why those who consume the most resources, have the most money and the highest per capita ecological footprints, tend to live in clean environments and, most importantly, enjoy by far greatest access to the so-called eco-friendly technology that so many speak warmly of (Hornborg, 2011). It also helps explain why toxic and severely polluted areas are typically inhabited with people that have very limited access to money and modern technology. What makes matters worse, according to Hornborg, is that the so-called 'green' technology is not only reserved for the rich segment

[7] Over the past decades the complex relationship between political ecology and Marxist economic theory has been vastly discussed (see e.g. Benton, 1996; Burkett, 1999; Foster, 2000; Foster & Holleman, 2014; Hornborg, 2001ab, 2014, 2015; Martinez-Alier, 1987; O'Connor 1998). Hornborg is obviously a proponent of radical critiques of capitalism and sympathetic to Marxism in that respect. Yet, he has extensively criticized Marxist *theory* for its inability to adequately analyse environmental injustice (e.g. Hornborg, 2014, 2015). Hornborg is not only critiquing the Promethean bias in Marxist scholarship but also the inclination to explain ecologically unequal exchange through the vocabulary of Marx' labour theory of value. According to Hornborg, Marxists confuse physics and economics when they define asymmetric transfers of biophysical resources in terms of underpaid 'use values'. Hence for Hornborg the main issue in the struggle for global environmental justice is not under-compensation: "Ecologically unequal exchange cannot be made equal by raising the price of resources, but it can be alleviated or even stopped. Following the same line of argument, we can conclude that ecological debt cannot be paid, only prevented from increasing" (Hornborg, 2015, p. 191).

of the world's population but it is also, in practice, subsidised by the fossil energy economy (ibid.).

A related serious crux is that a capitalist market economy, oriented towards increased material accumulation and production, inevitably generates raising levels of energy conversion which, in accordance with the second law of thermodynamics, causes entropy (or material disorder) to increase, e.g. in the form of carbon dioxide (e.g. Hornborg, 2001b, 2009, 2011). Hence, capitalism is essentially structured around import of energy and export of entropy. This contradiction between a growth-oriented money economy and basic thermodynamic conditions suggests that the prerequisites for reconciling economic and technological 'progress' with environmental concern, as epitomized in the whole notion of 'sustainable development', are bleak.

Ultimately, this all means that hopes in new 'green' technological solutions are illusory. What we need is not primarily new technology, nor associated technical knowledge or engineering ingenuity, but rather a new political economy. Hornborg has actually devoted considerable time to ponder what the properties of a more equal and less wasteful and transport dependent economy might be (e.g. Hornborg 2011, 2013, 2017). A central conclusion is that we have to reconsider the very notion of *money*.[8] General-purpose money, Hornborg argues, reflects the destructive idea that all values are commensurable. It basically makes it possible to exchange 'rainforest for Coca-Cola' (Hornborg, 2013, p. 123). Moreover, as indicated above, current possibilities to exchange natural resources and energy for finished products on the world market have the perverse effect that the more resources industrialized areas dissipate today the more resources they will afford to dissipate tomorrow. This economic system inexorably increases total entropy and Hornborg rhetorically poses the question of which of the following two factors mankind can do something about: general-purpose money or the second law of thermodynamics? What Hornborg proposes is thus that we change our monetary system towards a 'bi-centric economy' (Hornborg, 2011, 2013, 2017). One kind of currency – e.g. distributed as a form of citizen's salary – could be used for that which can be produced locally, i.e. products and services that do not require global circulation and division of labour. Essentially these are most of the things that we actually need for our wellbeing such as food, heating, basic goods and services. Another kind of currency could be used for products that have to circulate globally such as medicines, information technology, et cetera. According to Hornborg this would not only drastically reduce transport and wasteful resource use but also have positive social effects such as reduced unemployment, less social exclusion and less vulnerability to economic crisis.

In the foreword to one of his books Hornborg (2012) anticipates critique. His brief remarks serve as a rather useful end point here. In this foreword Hornborg first stresses that he is not hostile towards modern technology in the sense that he does not appreciate everything it can do to facilitate everyday life. He is only concerned about the fact that it cannot be made accessible to everybody *and* that we do not recognize the extent to which it is developed at the expense of people and environment somewhere else. Thereafter he clearly articulates that he does not claim that *all* technological efforts to enhance efficiency are mere illusions that *always* entail losses of time and resources somewhere else in the world system. Rather, he stresses, the point is that these harsh realities apply to such a huge extent that we have every reason to question our faith in technological solutions to the world's

[8] As indicated above Petrina and O'Riley (2001) have reached similar conclusions drawing on the work of Schumacher. Notably Bowers has also brought attention to the destructive elements of the money economy albeit from a different outlook (Bowers, 2011).

environmental and inequality problems (Hornborg, 2012, p. 9). This brings us to some implications of the present article's overall argument.

Conclusions

This article has reviewed mainstream and more critical work within the emerging field of technology education for sustainable development. Furthermore, the paper has attempted to challenge and supplement this existing body of research by offering a radically different outlook. This exercise is not an end in itself. Rather, it is an attempt to invigorate productive discussions amongst scholars, teachers and students. In this final section I will elaborate on two implications of the paper's argument. The first concerns scholarly debate and the other the curriculum.

First, there is a need to redirect much of the academic debate in technology education for sustainable development. It has become commonplace amongst scholars within this field to position their own work against, and trying to offer innovative alternatives to, crude forms of industrial modernity. Obviously there are differences in terms of how the prospects for 'green' technological solutions are contextualized and discussed, ranging from mainstream to more critical views. However, at the end of the day, the vast majority of scholars in this field (mainstream and critical alike), appear to agree that technological innovation is our best bet in the quest for sustainable development and that technology education has an important role to play (for an exception see Petrina, 2000a). The outcome is by and large a conversation between fellow proponents of technology. Arguably more interesting debates could emerge if scholars concerned with technology education for sustainable development spent more time responding to – or engaging with – the arguments of those who seriously question technology's ability to deliver environmental and social sustainability. Such a polemics proper is thus called for.

The second conclusion relates more directly to the curriculum of technology education for sustainable development, be it at the university level or at the school level. 'Technological literacy' has frequently been emphasized as a key objective of technology education. While the meaning of this term is contested (e.g. Ingerman & Collier Reed, 2011; Dakers, 2006) there seem to be broad consensus today that it goes well beyond capabilities to master technological devices to include understanding of relationships between technology, individuals, society and the environment in different contexts, as well as capacities to think about technology in multiple ways. As noted by a range of technology educators – including some of the works reviewed here – the latter surely must include more sceptical and critical takes on technology (cf. Kahn & Kellner, 2005; Keirl, 2006). Hence, regardless of whether one sympathises with Hornborg's understanding of technology as a means for time-space appropriation, it seems reasonable to suggest that exposing students to such a critical conceptualization is didactically relevant as it would broaden their theoretical repertoire and supplement conventional thinking about technology, thus contributing to technological literacy in the wider sense.[9]

Some scholars have also convincingly argued that understanding of technological *systems* is an important propriety of technological literacy, implying that technology education ought to foster capabilities to grasp the complex 'wholes' beyond a system's

[9] Petrina (2000b) has made a case for *critical technological literacy* as means to sensitize students to the politics of technology. For Petrina a turn to critical technological literacy ultimately means 'working to overcome forms of power sustaining inequalities in the built world' (Petrina, 2000b, p. 182). However, while sympathetic to Petrina's cause, my point is that knowledge of critical conceptualizations of technology ought to be an obvious component of any technological literacy worthy of its name.

constituent parts (Svensson & Ingerman, 2010). If we sign up to this idea, and if we are concerned with sustainable development, certain consequences seem to follow. It suddenly appears highly relevant to consider the *global* system of resource flows that enables technological 'progress' in some areas of the world and how this relates to the conditions of people and environments elsewhere. Hence, we must think carefully about whether so-called technological 'solutions' are tied up with environmental load displacement and ecologically unequal exchange. The bottom line is that technology education for sustainable development *also* – i.e. alongside the mainstream discourse about eco-innovation – ought to make room for critical and system focused perspectives. Bringing in such inconvenient voices into the curriculum could invigorate a healthy discussion amongst teachers and students about the prospects for a 'green' modernity.

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