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The political economy of flex trees : a preliminary

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Abstract

With the rise of 'bioeconomy', trees are receiving increasing attention. This contribution conducts a preliminary analysis of the trajectories and the main drivers of change in the rise of new, flexible and multiple uses of trees. It assesses the political dimensions involved in this transformation, which is simultaneously ongoing, anticipated and imagined. Notes are offered on the issues to be considered when the flex-crop framework is operationalized to include the study of trees, and additional conceptualizations that help in analyzing the political economy of tree uses are provided. Areas needing further empirical study are identified and a preliminary research agenda is suggested. The flexible and multiple use of trees and tree-derived commodities is having a large impact on power relations in the global political economy of forestry and the forest industry, the asymmetry of which is based on who is best able to flex or de-multiply, thereby controlling commodity webs and processing technology. It is argued that while flexing seems to increase diversity, in practice it typically increases this only for the processing industry; the converse occurs in terms of the unification of the productive base into monocultures. However, these two processes go hand in hand, and illustrate how flexing is a deeply capitalist process.

Keywords: forest futures, flex trees, global forestry, wood products, 'forest biorefineries', carbon sinks, wood-based energy, GM trees, green economy, flex tree plantations (FTPs), capitalism, commoditization

Introduction

The cultivation of crops that can be flexibly used for multiple purposes has been a growing trend in recent decades and is accelerating as new uses are found, developed and established for harvests that are conventionally used for other purposes (Borras et al. 2012, 2015). Studies examining the political and economic changes brought about by these flex-crop commodity markets have noted, for example, that a growing proportion of palm oil and soybeans is now used for biodiesel and other energy production, rather than simply in the food industry (Overbeek, Kröger, and Gerber 2012; Oliveira and Schneider 2014), while sugarcane provides ethanol alcohol fuel (McKay et al. 2014). Thus, new pathways exhibiting increased degrees of 'flexible-ness' and 'multiple-ness' (Borras et al. 2015) are being created in the contemporary capitalist 'bio-economy'. When analyzing this phenomenon, it is helpful to differentiate between 'tree flexing' (connected with the various elements

and species of trees) and 'tree-derived commodity flexing' (connected with the different end uses of the lumber, pulp, lignin and so on).

The rush towards flex trees is not uniform, however; different tree species, their parts and tree-derived commodities already have a multitude of uses and options, while the control of the biomass supply, essentially linked to land tenure, is still a key issue. Who produces, what, where, why and how are fundamental questions concerning rural power relations and political economy, as are the four questions suggested by Bernstein (2010): Who owns what? Who does what? Who gets what? What do they do with it? By providing answers to these questions, the power play involved in tree flexing becomes more visible. In the flex crop analysis suggested by Borrás et al. (2015), the concept of flexible-ness guides attention towards a new capital accumulation strategy, raising analysis from the level of mere bio-physical and technological change. When reviewing the literature on new tree uses, it becomes clear that the incorporation of analyses of power and capital accumulation are vital to understanding, and this contribution constitutes a preliminary step in that direction: I survey the bio-physical and technological state of affairs, but also illustrate how increased multiple-ness and flexible-ness change the paths of accumulation and power relations in the field of industrial forestry. 'Forest biorefinery' is one investment concept that encapsulates how flexing is occurring in forestry, but this is not the only path. For many the change towards conceptualizing forest biorefineries as the hub of flexing is mostly a narrative that legitimizes the increasing pressure placed by forestry upon the environment and society. For instance, a pulp investment program can be better marketed as a biorefinery that also produces bioplastics than simply as a project that consumes trees (and drives the conversion of forests into tree plantations). While this may promote innovative flexible-ness – which has not yet materialized – real flexing involving tree use is already taking place in the forest sector. Second-generation tree biorefineries, for example, are being linked 'upstream' into multiple feedstocks (different trees, all parts of the trees, food waste and other biomass) which are then flexibly converted into multiple new products (Näyhä, Hetemäki, and Stern 2014; Näyhä and Pesonen 2014): servicing the textile and energy industries and being turned into fish and poultry feed, besides producing conventional pulp (Ruokangas 2015). Such moves are recasting the production, circulation and consumption – and the links between these – of the flexed commodities. (Borrás et al. 2015)

This paper outlines some of the key issues to be considered when operationalizing the flexing

framework for the study of trees, demonstrating that much of the ‘green economy’ hype in the new flexing boom may be unduly optimistic, or even misleading: some flexing pathways still lack the technology, profitability or material basis required for their realization. Even if these are attained, the sustainability and ethical aspects of flexed production are not certain as the political and socio-environmental consequences of the turn have not received critical attention in terms of agrarian political economy. Much of the storyline has been cast as the resurgence of a fading Northern forest industry, a ‘green’ solution to the depletion of fossil fuels and, indeed, a win-win situation (e.g. UNECE/FAO 2013), but this is currently giving way to a more nuanced view, and the tendency to ‘de-multiply’ existing and potential forest, and tree and tree-derived commodity, uses, thus controlling flexing options through control of the material basis. In practice, capitalist tree flexing typically increases diversity only for the processing industry, while the productive base is unified into monocultures.

I address the minimum three factors necessary to the concepts of ‘real, anticipated and imagined’ flexing (Borras et al. 2015): material basis, technology and profitability. My main argument is that the new technologies of tree flexing (i.e. biorefineries) and an increasingly uniform material basis (i.e. fast-wood tree plantations) are two sides of the same coin of increased profitability, exposing how flexing perpetuates and deepens old power relations and is supported by accompanying ‘flex policy narratives’.¹ Several new concepts are also introduced – such as ‘de-multiplying’ (with regards to use and therefore flexing possibilities) and ‘flexing paths’ – and suggestions made for their operationalization in empirical research on the subject.

There are already a large number of tree ‘products’: energy, lumber, fiber, ‘carbon sinks’, new industrial products, and animal feed and food industry additives. Trees also have many actual multiple uses, the number of which fluctuates both as a result of new ‘technological possibilities’ and through new species and varieties that transform the ‘material basis’ of multiple-ness. In addition, changes in technology, material bases and profitability can either increase the flexible-ness (interchangeability) of particular tree uses, or ‘de-multiply’ them (which decreases the possibilities for interchangeability, an economic decision based on the available options), the latter being helpful in controlling markets. However, typically, multiple flexible uses would seem to be the obvious aim (Borras et al. 2015), allowing a wide portfolio with product lines whose markets do not correlate

but, rather, form a zero-beta portfolio.² Trees offer better possibilities for multiple flexible uses than, for example, sugarcane, as they have important side products and residuals that are already produced in mills but whose full range of applications has not yet been tapped.

The first two sections address the 'why', 'where' and 'by whom' questions and provide analysis of global asymmetries in the material basis, technology and profitability of treeflexing; in the third, I study whether and when trees serve as a material basis for multiple-ness and flexing; in the fourth section attention is directed at profitability; the fifth section answers the question of 'how' by exploring different paths and new technologies and their role in real and anticipated flexing; in the sixth, I use the example of 'carbon sinks' to contrast 'narrative flexing'³ with 'tangible flexing', concluding with a discussion of the winners and losers in tree-flexing.

Why? Flexing as a capitalist process

Capitalism is preceded by new ideas that make new paths of accumulation possible: a key tool is the quantification and universalization of particular aspects of nature as 'natural resources' or 'environmental services' with value, sought to be appropriated (Moore 2014). Flex narratives and new ideas precede accumulation. Here, I study trees as bundles of relations of science, capital and power, 'rather than geo-biological properties as such – without of course denying these properties' (Moore 2014, 14, italics in original). There is a long world-ecological history to the changing use of trees, focusing on the increasing power of the cores of global capitalism and the capitalist world-system to change the destinies of forests in the frontiers of 'cheap trees' (Wallerstein 1974; Carrere and Lohmann 1996; Moore 2010). New technologies and logistical networks, when applied at the industrial scale, massively transform forests, while the flexing approach can cast new light on the importance of 'natural resource' creation and distribution, the invention of technology and the establishment of trade networks as creators of power, development and accumulation. When Amsterdam built its global hegemony in the seventeenth century, it needed to create several tree commodity frontiers: Norway and Poland were logged, while the forests of Finland and Sweden were turned into tar (and later potash), as the transportation costs were too high at the time for exporting them as lumber (Moore 2010). In Finland, 'potash export peaked in 1820–40, but declined close to nil with the rise of a

strong domestic forest industry, which found better uses for wood' (Kröger 2015a, 23).

The invention of wood-based papermaking in the nineteenth century opened up the possibility for greater accumulation in forested regions by multiplying tree uses (Kröger 2010), although the turn to this form of adding value took place only after political mobilization against land grabbers wanting to continue to log the forests and sell the logs without prior processing (Kröger 2013a).

Today, large forestry multinationals such as Stora Enso or UPM have the capacity to produce everything from pulp to paper, cardboard, sawnwood, energy-wood, wood fuels and other wood products. It is not coincidental that these behemoths are mostly situated in geopolitical regions where political economic struggles first managed to increase capital accumulation based on flexing, which in its turn relied on rural power struggles that forced a drastic change from limited industrial tree use to more varied, higher value use.⁴ It is also not coincidental that the largest increases in flexing power (in terms of patented technologies, sales of flexing machinery, innovations and so forth) take place in those regions of the world (the North) that have been able to impose a forestry model upon the rest (the South) that serves the needs of the core in terms of offering 'cheap trees', rather than supporting the thrust of the full range of flexing capacities also possible in the periphery.

Drawing on Marx, Arrighi (1994) argues that capitalism has two cyclical phases of accumulation: money capital (M) and commodity capital, or increase in the trade of commodities of all sorts (C) (often requiring territorial/material expansion). Once capital is over-accumulated within a marked territory by technological development, innovation or increased money capital accruing from financial deals, it can no longer maintain high levels of returns. This leads to a need to invest capital and capture resources through territorialization/materialization, or to engage in commodity trade to increase money capital gains: the ultimate goal in capitalism. Flexing is part of an M-C cyclic change, where over-accumulated money capital desperately seeks 'flex narratives' to identify where to invest in order to join the C-cycle and increase trade via multiple-ness and flexing of existing commodities. In earlier centuries of capitalist frontier expansion, new exotic commodities were inserted into the capitalist world system from conquered territories. Now, as capitalism is an M-C-M cycle-dependent process, and as local populations are resisting the global land rush of recent years, the expansion dynamics of the physical commodity

frontier have in many places (such as Brazil and Indonesia) approached a situation of frontier closure (Tsing 2005; Kröger 2015b); consequently, new paths of commodity increase are required. Enter flexing.

Towards the late 2000s, a number of factors began to impact on the Northern forestry industry: 'cheap trees' from the global South, increasing domestic growth rates and ample by-products, constraints in terms of high prices and distributed forest control, expanding technology, and low profit margins which had the effect of spurring the need for new business development. These conditions explain why 'tree-derived commodity flexing' has surged among those active in forestry capitalism in the global North (e.g. paper companies). In the South, the higher growth rates (but of more limited tree species and more restricted usage of their parts, yielding fewer side products), restricted technological capacities and higher profit margins (thus a less pressing need to develop new businesses) explain why Southern actors (e.g. logging, pulp and energy-wood companies) have engaged less with flexing.⁵

Where and by whom? Global asymmetries in tree-flexing power

Flex trees are the commodity consequence of merging inter-industry interests in the emerging global 'bio-economy' which is not unfolding similarly everywhere, as illustrated by the uneven geographical distribution of flexing paths. The mature, traditional forest industry strongholds, such as the European countries and Canada, for example, with their competitive advantage in fixed capital and established technology, may be compared with the rising 'plantation powers' of the global South (e.g. Brazil with its massive tree plantations) with their powerful material basis. Here, I discuss some exemplifying cases: the total global distribution of flexing paths should be studied in detail in future research.

Global North

In the global North, the first wood biorefineries started production in 2014 (in Finland), alongside major pulp and paper plant complexes. New industrial uses utilizing new technologies are being developed for wood, particularly in construction and durable material sectors where the wood-based revolution is ongoing and expected to continue. Examples of this latter trend include extremely durable wood-based construction materials used in the three-dimensional printing of wooden houses, and for extra-hygienic wooden surfaces (Linturi, Kuusi, and Ahlqvist 2013). A group of Finnish universities and companies, including

UPM (a Finnish timber, paper, pulp and energy corporation created by the merging of Kymmene, Repola and United Paper Mills in 1996), has also engineered the world's first high-safety, mass-produced car made entirely from wood, and weighing 15 percent less than its conventional counterparts. Furthermore, the vehicle is compatible with UPM's biodiesel fuel, meaning that it could represent a fully forest-sourced product (Nikula 2014).

Traditional forest industry regions, such as Scandinavia, have large industrial complexes which integrate all these uses in the same locale, and which are investing in an even greater flexing and multiple-use of trees, including pulping, sawmills, paper mills, biorefineries and power plants. These hubs and the companies owning them are able to flex on multi-scalar levels, rather than merely increase the number of (commodity) tree uses, and they are already doing this. Future studies should analyze in detail the reasons why companies decide to switch between using trees for different purposes and in making use of both new and old capacities for interchangeability.

Besides these technologies, wood-plastic composites (WPC) and cross-laminated timber (CLT), which are useful new construction and industrial materials, are also heavily concentrated in a few European countries, with further technology development taking place in Canada and the USA (UNECE/FAO 2013). In this sense, the flexing of trees seems to follow the historical North/South technology development pattern. In addition to an increase in the technological or vertical depth of flexing via these pioneering flexing hubs, we are likely to see, as the second stage of flexing advances, a sale of slices of the new technologies to the rest of the world, for purposes that are only curtailed by the tree production political economies in the investment areas.

Global South

This horizontal expansion of flexing is now unfolding, for example, as the growth of pulp, energy and biofuel mill complexes in South American industrial tree plantation areas (particularly Brazil), without the presence of either the sawmill-derived product chain and flexing (eucalyptus, pine and acacia from fast-wood plantations serve almost solely for making pulp, charcoal or energy-wood), or the specific flexing sub-pathways that are currently most strongly developed for Northern material streams derived from pine pulping (as discussed below). The global papermaking corporations/biorefinery technology providers are therefore offering the innovative capital goods to new flexing companies in the cheapest feedstock

production areas – but only to a certain degree, and for less valuable but more voluminous applications; the global South is mostly rendered a place for cheap-tree energy and pulp production. The discrepancy observable between North and South investment notices suggests that the technologies of flexible-ness and multiple-ness that deepen this North/South divide are sold to the South and built there, while the development of applications directed towards the potential of higher added value is concentrated in the North. However, studies should retrospectively assess this hypothesis in greater detail a few years from now. While technology development, particularly in relation to machinery, is still largely controlled by Northern companies, fast growth and flex plantation techniques, including genetically modified (GM) trees, are an area of innovation whereby rising Southern forestry corporations such as those in Brazil (e.g. Suzano, Fibria) are gaining a strong foothold. Tree plantations (TPs) are becoming flex tree plantations (FTPs) which are primarily a flex narrative through which new and old forestry capitalists address the depletion of resources by framing TPs as ‘renewable’, ‘bio’ and ‘non-food’ commodity-flexing sources, and therefore supposedly more ethical than minerals or first-generation biofuels. While there is an overlap, the main geographical cleavage line in flexing potentialities is rooted in the North’s advantage in pursuing profitability through technologies that multiply endproduct processing, and in the South’s larger, faster rotation, and thus more material basis. The contention in this contribution is that the main reason for the division of flexing geographies is that different regions have different industries and landholders directing wood use and forest policies. Analysis of flexing should start, therefore, with examination of which land/forest-using sectors and sub-sectors have the greatest power to steer policies in given political economies, rather than with the possibilities offered by technology or the material basis, as transformations occurring in the latter – and their impact on profitability – can best be explained by the power relations connected with land and nature control.

If and when? Material bases and constraints in tree flexing

There are many different material aspects particular to trees that researchers must consider when applying the flex-crop framework in their analysis: this section canvases in turn the dimensions that should be examined in the course of such research.

Different tree parts

Different tree parts, particularly in large trees, serve multiple purposes: (1) the log or trunk

can be turned into lumber (sawnwood), plywood and other timber for the construction and furniture industries, or burned or pulped; (2) the thinner, non-log parts of the trunk cannot typically be used as lumber, but are usually pulped to capture the wood fiber and numerous side products with increasing flexible applications, including tall oil, black liquor and turpentine; (3) the woody parts which do not typically serve for lumber or good pulp, such as bark and branches, are used for energy products (Schulze et al. 2012). Thus, not all parts of the tree can be flexed between all processes, something which increases the incentive for multiple-ness in tree uses.

This multiplicity of distinct, usable tree parts has several important impacts on flexing. First, tree owners typically get a far better price for logs than for pulp or energy-wood; consequently, they seek to sell all three of these wood parts in the end harvest. The prices calculated for each sale follow different market logics which are now both challenging, and being challenged, by new flex trees. In Finland, about half of all fiber-wood comes from end harvests whose logic follows the price of the log and not that of fiber-wood, which currently offers a low return for forest owners – mostly family farmers in Finland (Kröger 2013a). This means that most of the pulpwood/fiber that the new massive biorefineries require is subject to a bottleneck that may endure until the number of local sawmills is dramatically increased: for each 1.1 million tonne pulp mill a 0.8 million cubic meter capacity sawmill would be required (Taloussanomat 2015). These sawmills would also need to have the money to buy the logs for processing, which means that much of the fiber-based flexing pathway is pegged into developments in the sawnwood pathway. Currently, the pulp industry is trying to tap into source 3 above via improving the usability of wood chips in making good pulp (and side products) (Lam 2015).

Second, to overcome this natural limitation, companies have sought uniformity in forestry practices to get only one or two of these products. The ITP pulp plants in the global South, which are controlled by corporate land ownership, escape the dilemma above, as they own or otherwise control the land and thus do not produce logs as the pulp mills do not need logs; nor do they have to compete with the buyers of the other tree parts (numbers 1 and 3) (Kröger 2013b). Third, as a total flexing across the different uses of all tree parts is difficult, impossible or unsuitable in current practice (the quality of the end product is considered poor), deeper development has taken place in flexing subpathways

for all three tree parts during the processing phase, as profit-maximizing tree sellers and buyers explore their fullest use.

Different tree types

There are also other factors concerning trees that make the study of their flexing more complicated than that of oil palm, sugarcane or soybeans: a major issue is the huge number of tree species, of which at least two broad categories should be distinguished even in generalizing global studies. Softwood refers to gymnosperm trees such as conifers (e.g. pine, fir) – these being the major source of timber production and concentration in the global North, while hardwood refers to dicot angiosperm trees which are typically broad leaved (e.g. oak, teak, mahogany, eucalyptus, poplar, birch) whose industrial production is increasingly concentrated in the global South. The flexing of softwood at the cost of tropical hardwood has become a trend based on the North's having the upper hand in fixed capital and in building new technology on top of their patents: 'Innovations in product development and processing have generally benefited softwoods and other materials rather than tropical hardwoods, with global research focusing on improving the ability of softwoods to match the technical performance of tropical hardwoods...' (Maplesden and Johnson 2013, 74).

Flexing based particularly on pine in the global North has meant that in the illustrative and important global forestry case of Finland (developments there having strongly impacted global practices historically, see e.g. Sonnenfeld 1999; Kröger 2013a), for example, a part of the pine harvest previously used for lumber is now increasingly used for making pulp. Between 2000 and 2014, the cubic meters of pine logged for lumber decreased by 15.8 percent (1.9 Mm³), while the logging of pine for pulp increased by 21.5 percent (2.8 Mm³); firs or angiosperms did not portray such notable flexing in their distribution between lumber and pulp during the same period in Finland.⁶ While some of the pine flexing from lumber to pulp in Finland came from new-growth pine stands, it was mainly due to a change in harvesting practices whereby lumber harvests decreased significantly for all tree types, while fiber harvests increased for all trees except firs (in other words, pines were logged younger and thinner).

The flexing from pine lumber to pine pulp in the taiga between 2000 and 2014 was largely a result of the eucalyptus pulp boom in South America and Southeast Asia. Both softwood and hardwood are required to make good paper – softwood fibers provide

tensile strength and hardwood fibers opacity – and softwood demand in the global North increased with the entrance of a massive new supply of hardwood pulp which drove the change; furthermore, it is expected that Northern pine pulp will attain high value as the result of future increases in flexible-ness and multiple-ness mentioned above. However, competition from the South for Northern softwood pulp will increase.⁷ A global assemblage of forestry practices influences the type of material basis available for regional flexing, and should be studied to trace back the links between change in material bases and technologies.

⁸ The flexing described above has principally been instigated by the large paper multinationals, who produce both softwood and hardwood pulp and lumber in the North and South, and whose buying decisions give them the power to decree which trees are planted and when they are cut, what parts are used and for what purpose.

Different-sized trees

New flexing capacities and markets may dramatically change the destined use of forest lands, promoting the cultivation of either thinner or thicker trees based on market fluctuations. The potential for construction and industrial wood flexing, for example, which typically requires trees with a diameter of at least 18 cm, is limited in some regions due to the dominance of the pulp investment boom (Kröger 2013a, 2013b), which relies on fiber-wood harvested at less than 18 cm and replanted. Energy-wood is typically below 9 cm, though larger diameter trees can also be used for both energy and fiber production. Plantations of small-diameter trees do not afford such a wide array of flexed-ness and multiple-ness as semi-natural forests or tree plantations that are thinned regularly but whose main cubic meter bulk is left to mature into lumber. As TPs have expanded, there has been a trend towards installing new heating power plants and pulping facilities that further thin the diameter of trees logged.

Future analyses of tree flexing must consider how flexible-ness and multiple-ness in the use of different tree parts change in different industries and market regions across time. Figure 1 illustrates one such analysis, showing how investment in heating power plants in Finland has led to a rapid rise in the use of pulp and fiber-wood (small trees) and other tree parts between 2000 and 2013.⁹ Heating power plants can select from a variety of feedstocks, based on market prices and availability, and increasing investment in them has meant that all tree parts mentioned in Figure 1 have been flexed to this new use,

either from old uses or from non-use (where left as forest).

Differing rotation cycles

It is also essential to separate TPs and (semi-)natural forests in the study of the impacts of the material basis on flexing: particularly important is the rotation cycle, which is typically about 60–80 years in the semi-natural forests of the circumpolar North, while only 2–10 years in the TPs of the tropics and sub-tropics; this naturally results in greater flexibility in the material basis of the latter. Fast rotation means that, if needed, plantation wood producers can, with access to the right species and varieties of trees, avoid ‘de-multiplying’ the use options of their material basis, a path whereby the possibility of flexing a commodity is decreased: for example, by having to wait decades for trees to be ready for harvest before being able to change the planted variety. While a fast-wood TP can be harvested quite quickly, and a different variety more suitable for new industrial lines be planted, the same is typically not true for tree stands in the North. These differences promote a flexing path that is more reliant on material bases in the tropics, while the slower growth of the temperate zones encourages greater technological tweaking.¹⁰

Increased flexing (and de-multiplying) options can be ensured by the traditional means of corporate land control, whereby those who control the material basis may dictate whether only eucalyptus is planted, or whether a more varied – and therefore more flexible and multiple-use – tree base is established. The selection of species has indirect future impacts for flexing with, for example, eucalyptus somewhat de-multiplying the possibility of using the same or adjoining land later for agricultural or other forestry purposes due to its negative effects on soil and water balance (Kröger 2014). Fast rotation and other forestry practices are thus the keys to understanding how flexing pathways are strongly delineated by changes in agrarian practice and land use.

GM trees: low- and high-lignin flexing paths

The pulp industry has tried to develop tree species with low lignin content because, if lignin is not removed, paper becomes yellow with time, but it is an expensive process typically using chemical pulping. Trees with lower lignin content are also more suitable for conversion into biofuels, encouraging the development of, for example, GM poplar trees that fit this profile (Ye 2011), while US producers have argued they could generate about 9.1 billion gallons of fuel with the right GM trees’ woody biomass (United States Government

2009). But while low-lignin GM trees seem to open up possibilities for cheaper production of paper and biofuels, this change in materiality de-multiplies traditional multiple tree uses wherein lignin is a key component of multiple-ness. Lower lignin content GM trees store less carbon, while lignin, when removed, has myriad other niche applications: for example, it is already being used to replace oil in dispersals, additives, chemicals, plastic, carbon fiber and fuel (Nelson 2008).

The pulp and energy-wood producers of the global South seem to have chosen the path of low lignin which involves higher initial flexing (tree-based), lower multiple-ness and thus lower long-term flexing (tree-derived, commodity-based) potential. For example, the eucalyptus hybrid in use in Uruguayan pulpwood ITPs was engineered by Shell to have lower lignin content (Kröger 2010), which means that there will be less lignin-based multiple-ness and lignin flexing in local pulp plants. Suzano's FuturaGene GM tree company has developed and is now planting low-lignin, fast-growth GM eucalyptus in Brazil, to be used mainly for pulp and bio-energy. The value of material bases utilizing high-lignin trees is increasing due to the technology-flexing trend, but would be decreased if low-lignin (GM or hybrid) trees were planted instead. Thus, if a company aims to produce just paper or biofuels as cheaply as possible (in terms of energy and industrial technology), and ensure the tree stock is not of use in other applications, the company could distribute low-lignin varieties to delimit the growers' customer base. This would also decrease the material basis for paths based on 'cheap lignin' sub-path flexing.

As lignin is an increasingly significant by-product of pulp-making and the basis of considerable sub-path flexing (at the mill), those in control of land and what is planted there can de-multiply the tree-use options of those who are downstream in the value chain. Paradoxically, planting a GM variety that can be more profitably turned into biofuel or pulp than a non-GM tree de-multiplies tree uses in the general picture.¹¹ Thus, although GM trees are often marketed as a tool for increasing possibilities, the opposite seems to be true, with GM trees shifting prior uses to the less flexible avenues preferred by particular groups. In these power struggles, those who have land and can control the choice of material base are in a de-multiple-ness versus multiple-ness/flexed-ness battle with those with fixed capital who control industrial technology. Indeed, the struggle between the material and the technological basis that already exists in the industry, and its cleavages, is a vital and fascinating topic

and deserves careful analysis and theorization.

The 'default' and 'non-action flexing' options for trees

Trees are inherently more flexible than crops in the sense that, even if they are not harvested, they may retain and increase their value for longer, offering the 'non-action flexing option' of just 'letting' the trees 'increase carbon storage' (at least discursively, and possibly in carbon markets, if not in reality), while retaining recreational and nonindustrial foraging uses. Trees are thus flexed 'by default' in comparison to other crops.¹² Typically, this default option increases flexing and multiple-use possibilities (up to a certain limit): trees can be left to grow as a flexible stock, without the need for storage space or fear of spoiling in the same sense as other crops. On the other hand, wildfire, storms and other natural hazards, along with resistance-boosted actions like arson, are also increasing in likelihood, due both to climate disruption and to the grievance-generating expansion of TPs to food-producing regions or indigenous lands (Carrere and Lohmann 1996; Kröger 2014). Thus, agrarian political economy and political ecology, where nature is an agent, must be included in analysis. As capitalism continues to commoditize tree uses, the physical spaces where neither violence nor surveillance is on the agenda are reducing in number. This suggests that capitalist flexing decreases the possibilities of 'default flexing' offered by naturally grown forests, another subject worthy of further study. I next turn to the profitability element of the 'if and when' question.

If and when? The role of profitability in flexing trees

Although specificities and flexing-option differences in cost structures should be empirically validated and reviewed in detail in future studies, in most regions the second pillar of flexing – profitability – seems to be more easily, readily or necessarily attained by tweaking the material basis via new forestry policies. This is because biomass feedstock still dominates the cost structure in most sectors of the forest industry and across different countries (although there are deviant cases): for example, Trømborg (2013, 73), comparing pellet production costs in four European countries and the US, found that 'the most effective way to cut production costs and raise profitability is to minimize feedstock costs' as expenses from feedstock and its transportation comprised, on average, 60 percent of the cost structure. In addition to pellets, the same kind of feedstock-

dominated cost structure also applies in many other forestry sectors, such as in pulp and papermaking (Kröger 2010). Meanwhile, ‘cutting capital, energy or labor costs has comparably small effects’ (Trømborg 2013, 73), although the industry in Scandinavia, for example, tries to portray labor costs as a large impediment to competitiveness.

Profitability can also be increased by tree-derived commodity flexing; using the case of Austria, Stern et al. (2015) argue that biorefineries would secure higher profits for the whole forest sector as sawmills, for example, could sell their residues to biorefineries and thus become more competitive. But other researchers emphasize that profitability depends on low biomass cost and/or a large-volume production plant: for example Pettersson et al. (2015) argue, using the case of Sweden as illustration, that siting is a key issue in securing a low biofuel cost structure. Most case studies suggest that the profitability of tree-derived commodity flexing is secured best when integrating new functions to large established plants, such as paper and pulp mill complexes (Pettersson et al. 2015). These findings support my prior claims that flexing replicates long-term North/South power cleavages whereby technology continues to accumulate in the North (as by far the greatest profitability increase is to be gained there), and the appropriation of nature continues to intensify in the South. This understanding leads into discussion of the third pillar, technology, and how flexing takes place.

How? Different technologies and paths

There are multiple pathways along which flexible-ness and multiple-ness of the industrial use of trees is currently being transformed globally. Table 1, row 1, summarizes the key routes, and provides examples of: (1) the changing pathways to tree flexing and multiple use (new technologies, column 2); (2) a non-flexing alternative (the narrative of ‘carbon sinks’, column 3); and (3) de-multiplying pathways (GM trees, column 4). The rows after the first one separate the key applications, methods, products, companies and interindustry merging ongoing through the particular flexing or de-multiplying pathways delineated in the columns in row 1. The lower rows go into the specifics of a particular path of flexing/multiple-ness: for example, new technological possibilities in tree flexing (row 1) incorporate the application of wood-based energy that changes flexible-ness and multipleness (row 2), through particular methods (biofuels and electricity and heating; row 3), and

result in particular key products (biodiesel, ethanol, wood chips; row 4), and particular companies operating within this flexing/multiple-use increase pathway (e.g. UPM and Fibria, Enviva; row 5), creating specific inter-industry merging (Chevron etc.) exemplified in row 6.

Technologically, it is possible to use a tree stand for producing biofuels (flexing method 1), electricity and heating (flexing method 2), lumber (flexing method 3) or fiber-wood (flexing method 4). Methods 1–4 all represent genuine flexing, and a wide range of companies already make use of them. It is also possible, however, to procure the material for some of these methods through the by-product of another method rather than through flexing; in this case the product is more the result of multiple-ness development than an increase in flexible-ness: for example, some biodiesel is produced from a pulping by-product. But direct tree-flexing also exists, in the form of new fuel plants that operate by processing any kind of solid wood into fuel, and the trend is to increase their capacity massively, which signifies that wood-fuels are emerging not just as a pulping sub-path (to be placed in row 4 under fiber-wood), but as a distinct, separate, flexing pathway. However, the case also illustrates that the multiple flexing sub-pathways are also converging, creating a complex ‘value web’ whose application and capacities to use material streams can change rapidly.¹³ But there is an important qualitative difference between the initial flexing-pathway choice made in row 3, between flex methods 1–4, and the narrative and de-multiplying options that accompany the choice.

The internal pathways (tree-derived commodities) for lumber (3) and fiber-wood (4) in the table are currently dramatically increasing both their flexible-ness and multiple-ness. Thus, it might be appropriate to say that a focus on lumber and fiber-wood, at the cost of biofuels (1) and electricity and heating (2) (both of which result in swift combustion), is a path to increased flexible-ness in this single field rather than increasing the full range of flexible-ness possibilities for all paths and all actors (between methods 1–4). Narrative flexing (column 6, row 3) operates differently, however, and can be combined with all methods 1–4, or, ironically, even with ‘de-multiplying’, if GM tree stands are accepted as ‘carbon sinks’.

Table 1 produces a generalized global picture. But countries differ in the way tree users

flex between tree uses, and future analysis should, for example, consider how the dynamics of Finland – where the paper and pulp industry is pivotal – differ from those of Central European countries or Japan where wood-products industries are more important (and have particular sub-sectors and dynamics that operate between them). Table 1 lists some key companies in each pathway, based on analysis of existing data, and future research should study each of these in detail, but discussion in this instance moves on to closer examination of particular flexing pathways.

From pulp mills to biorefineries

Pulp production has started to increase again in the global North, under new investment: pulp is a key augmentor of flexible-ness in trees because it can be utilized for multiple purposes, while pulping by-products are also acquiring more flexible uses. As noted above, tree-based biorefineries can produce bioplastics as well as biofuels, and the technology allowing for this conversion is rapidly advancing. A major Finnish forest-owners' cooperative corporation, and the world's largest softwood-market pulp producer, the Metsä Group, announced in April 2014 that it is investing 1.1 billion euros in a bio-product mill in Central Finland (Äänekoski) based on pine pulp production, an investment that would not have materialized without the assurance of future earnings from an increase in the flexibleness of trees. The company markets the mill that will be inaugurated in 2018 in the following way (Figure 2):

“The new mill will be the world's first next-generation bio-product mill that can convert wood raw material into a diverse range of products. In addition to high-quality pulp, the mill will produce bio-energy and various bio-materials in a resource-efficient way. A unique bioeconomy ecosystem of companies will be built around pulp production....Our new mill will be the most efficient and modern bio-product mill in the world. The global increase in the demand for high-quality softwood pulp is the most important driver for the investment The wood raw material and side streams will be utilised 100 per cent as products and bio-energy. The mill will increase the consumption of fibre wood in Finland by approximately 4 million cubic metres (some 10 per cent) per year.” (Metsäliitto Cooperative Company Announcement 2014)

Other similar biorefineries are also anticipated in Finland: in Kuopio (Finnpulp, with a planned yearly capacity of 1.2 million tonnes of softwood pulp, 60,000 tonnes of tall oil and

0.8 terawatt hours of electricity for the national grid: to be opened in 2019, this would be the world's largest softwood pulp mill) (Taloussanomat 2015) and in Kemijärvi, which is above the Arctic Circle. This case illustrates both the globalness of the new flexing trend and the stronger pressure that it places on formerly peripheral regions, or areas where forests experienced reduced pressure when the eucalyptus pulp investment boom of the 2000s moved production capacity to the global South (Stora Enso shut down a profitable pulp mill in Kemijärvi after it opened a more profitable one in Brazil). The Kemijärvi biorefinery project, principally developed by the Finnish state's Forest Centre, estimated to open by 2020, is marketed as employing 1000 people and costing 800 million euros (Ruokangas 2015). It is 'profitable and there is enough raw material' according to a Forest Center representative: competitive advantage lies in the large available quantities of softwood fiber-wood, which is experiencing increased global demand despite limited places where it can be produced. There is also an existing infrastructure although the project still 'competes with North America for investment'. These combined elements suggest that the trend of production moving to the South has passed and a new phase of North-North competition has begun wherein flexing technology development will be a major vector.

Biofuels as new products

Wood-based fuels are already a reality, particularly in those areas where fixed capital allows the fuel to be produced as a multipurpose means to exploit pulping residual rather than as a product of flexing. Zhang, Gilles, and Stewart (2014) estimate that global demand for woody cellulosic ethanol will increase substantially over the next 30 years, stimulated largely by the rising cost of gasoline.¹⁴ The current Kraft pulping cycle produces lignin as a residual (typically, 30 percent of wood mass is lignin) in abundant and under-utilized quantities, this being a bio-resource which currently represents a low-value energy source in pulp mills (Kosa et al. 2011). The Northern forest industry, therefore, has a considerable interest in developing the value-adding uses for lignin (many of which have been around for a long time, but have not been turned into product lines on an industrial scale), not only to augment the role of biorefineries, but also to further valorize the Kraft process, given that the industry has strong in-built political/economic interests in this technology such as sunk costs and control by a few key players.

In 2010 it was estimated that the first biodiesel pilot plants would be ready in 2014–2015, concentrated in Finland (Uronen 2010). The prognosis has been realized with UPM opening one in Lappeenranta in 2014 that works in roughly the same way as a traditional oil refinery, while using wood-based tall oil, a by-product of pulp manufacturing, as its crude. The company director anticipates high profitability and the expansion of wood biodiesel into a 6€ billion business. The new technology has already started to spread: the European Commission has awarded UPM a grant of 170€ million to build a solid-woodbased biorefinery in Strasbourg. While the pilot project was based on finding multiple uses for a residual that already had commercial application,¹⁵ thus representing tree-derived commodity flexing, subsequent investments can also tap directly into non-residual materials, such as bark and wood chips made from stumps that are not used in pulp-making and are therefore not its residuals but side-products, thus representing tree flexing.

Wood-based electricity and heating

Wood is also expected to become an even more important source of heating energy, with 55 percent of the global wood harvest already serving as a fuel for traditional bioenergy (Masera et al. 2015). In Finland, for example, wood accounted for about 24 percent of all thermodynamic energy consumption in 2012 (Metsäteollisuus 2013), while Aguilar et al. (2013) argue that wood represents 10–15 percent of the global supply. New heating and power plants have entered the market, leading to greater flexibility particularly in consumption of roundwood – and, to a lesser degree, secondary wood – by forest industries (including wood-products industries and pulp industries) and energy generation: for example, in Finland between 2005 and 2014 the rise in the use of roundwood for heating and power plants was 462 percent (rising to 4.16 Mm³), while the total amount of roundwood consumed remained roughly the same (about 73 Mm³) in both 2005 and 2014.¹⁶ Meanwhile, consumption by wood-products industries decreased by 4.6 Mm³ in the same period, which suggests that some of the roundwood once used to make wood products has been flexed into energy-wood usage during the past decade,¹⁷ a rising trend that is not limited to Finland: massive infrastructure construction is currently underway for the burning of biomass in Europe, the US and other countries (Lander 2012). However, the increased harvesting of forest biomass for electricity,

heating or bio-gasoline is neither sustainable nor neutral in terms of greenhouse gases (Schulze et al. 2012).

Pellets are the most widely traded wood-energy product globally, with the US, Canada and Sweden being the most important producers (Aguilar et al. 2013); since 2000 consumption has increased dramatically, in line with the goal of replacing oil heating. Europe dominates the sector: in 2010, 85 percent of global consumption was in the EU, encouraged by its biofuel policy incentives (Goh 2013). The expansion of the market for wood pellets is limited, however – boilers are expensive and it is often easier to burn bark or other wood products – and markets for pellets and wood chips are now bifurcating: the UK, Denmark and the Netherlands are examples of countries where the use of wood pellets has increased, while in Finland and Sweden, for example, the use of wood chips is proving more popular. One explanation is that pellets can be more easily exported, while chips should be gathered within 150–200 km of power plants, making them feasible only in forested areas (author's interview with the Finnish Forest Industries Association, Helsinki, April 2014). Furthermore, the powerful Finnish paper industry is against the flexing of trees for energy uses such as pellets, as this competes with its own tree use and biorefinery technologies. Consequently, substantial pellet-production investment in Finland has been cancelled, with the funds being channelled into other flex-wood operations such as biorefineries or pulping. Meanwhile, aspiring to economies of scale, other countries, including Russia, are installing enormous pelletization plants to supply the global pellet market, whose volume is expected to soar from the 2011 level of 12 million metric tons to 90 million tons in 2020 (Aguilar et al. 2013). Rising pellet exports have been criticized, however, for substantially increasing clear-cutting and forest damage in various regions such as southeastern USA (Hammel 2013), illustrating the immediate impact industrial-scale (tree) flexing typically has on nature.

Narrative flexing: the example of 'carbon sinks'

Clearly, the technologies described above have led to new tree flexing; there is, however, a considerable amount of narrativized flexing that never actually takes place, a trend particularly evident in attempts to commoditize trees into 'carbon', and then sell this fetishized 'product' in carbon markets (Lohmann and Hildyard 2014). REDD+/++ and Clean Development Mechanisms, for example, have been created in the course of flexing trees into a

narrative of 'carbon storage', manifest in the expansion of so-called 'carbon sink' tree plantations (Overbeek, Kröger, and Gerber 2012) – an illustration of how flexing can occur purely as capitalist and speculative fantasy (see Lohmann 2006), devoid of a basis in technological expertise or even profit.

Several points should be raised in this context: first, if technology may be considered here to mean global systems of carbon trading and vital concomitant carbon accounting and offsetting calculations, it is still underdeveloped – neither functioning correctly nor decreasing carbon (Bridge 2011); second, the forest industry itself is driving the harvesting and processing of trees, rather than pursuing 'carbon' flexing; and, third, 'carbon sinks' are not profitable even within the faulty logic of the current carbon trade regime (see Paul et al. 2013). Nevertheless, 'carbon sinks' are expanding, particularly in some African countries, India and Latin America, where lower returns suffice, as they spare companies the costs of relocating populations, for example, or rectifying damage caused to the environment (Overbeek, Kröger, and Gerber 2012). As with other types of flexing, it becomes apparent that the greatest business benefits of narrativization ensue from heightened expectations and the promise of potential, leading to increased speculative finance and political support for the industry; certainly, to date, 'trees as carbon capturers' is more of a legitimating discourse for TPs (actually being used for other purposes than 'carbon capture') than a real or anticipated flexing pathway.

So much for the narratives of mechanisms such as REDD+: what about the actuality of flexing trees for carbon-sink usage? First, a technological limitation lies in the fact that the measurement of tree carbon sinks is probably impossible, and certainly full of contradictions (see e.g. Lohmann 2006; Lohmann and Hildyard 2014). Furthermore, the practice of flexing in general has increased soil modification and intensified harvesting: the wood-based energy industry is particularly interested in the 'residual' materials that would otherwise be left on the forest floor. Nonetheless, the forest industry wants to portray itself as 'green' by virtue of the device of 'carbon storing' trees, although as a tree-producing industry it runs against its interests to allow trees grow as a 'carbon sink'. Yet, in spite of the technological and material problems of creating 'carbon' trees, some 'narrative flexing' of 'carbon' has occurred. In an epoch of global financial-

capital dominance and over-accumulation, where speculative and imaginary market bubbles are continually being created, even barely, or merely assumedly, profitable 'abstract natures' can serve in narrative flexing, although, if 'carbon credits' are sold, the 'flexing' becomes 'real'. In spite of the above points, and although the global carbon trading system has collapsed, carbon markets have expanded, according to Newell, Pizer, and Raimi (2014). The discrepancy between 'carbon' storytelling and using wood for new products demonstrates that narrative flexing can exist as a 'product line' alongside the more tangible use of the commodity, thus multiplying the use of wood as (1) abstract 'captured "carbon"'; and (2) tangible new products or energy. This suggests that narrative flexing and 'carbon trees' should be incorporated as a key avenue to be studied in future flexing research.

Discussion: winners and losers

There are winners and losers in flexing. Foraging populations that benefit from the rich biodiversity in forests that offer much more than wood – indeed, often a substantial part of their diet – will face tough pressure on their very subsistence once trees are more fully flexed and their uses multiplied industrially and globally into a thick value web. The winners of the flexing battle between capitalists are defined principally by the ease and brevity that a given flexing pathway offers for realizing the M-C-M cycle. The less time the new tree commodity spends as commodity capital and the more easily and quickly it can be turned into money capital, the stronger the flexing pathway. This goal is better facilitated by selling a bulk product such as wood-diesel or pulp, than by creating wholly new wood products, marketing them and finding buyers; the successful introduction of flexing therefore depends on strong agency input by sales personnel, forestry capitalists and scientists who can design uses for products created in the new biorefineries and other flexing hubs, and also make the connection between producers, buyers and policy-makers. Those with control over the largest array of flexing and multiple-ness pathways, and multiple feed lines, will have new competitive advantages, and flexing might allow major biorefinery owners to cut into the wood base of those, such as traditional sawmills and heating power plants, in need of roundwood and not able to flex as much. On the other hand, those investing only in wood-burning capacities can 'endanger' the wood-recycling

hubs of those operating in every other flexing pathway by cutting into the whole material basis (all tree parts can be burned). Ultimately, those controlling land are poised to retain a key role, despite all the advances in flexing technologies.

The centrality of biomass to profits underlines the understanding that replacement of native forests by global TP expansion is essential to comprehending the *longue durée* of tree flexing. Thus, the 'evental histories' of building pilot biorefineries in the North – ensuring technological potential – should not be over-emphasized at the expense of transformations in the material basis: technological flexing by wood-based biorefineries goes hand in hand with the expansion of FTPs, perpetuating global asymmetries where Northern technology dominates, and industrial capital defines preferred land-use policies (ITPs to feed tree-derived commodity flexing controlled by the North).

Concluding remarks

The flex-commodity concept was initially created within the perspective of global and general agrarian change (Borras et al. 2015); applying it to an interdisciplinary analysis of trees is, however, a fruitful method for addressing the complexities of forest transformation. Forest research has lacked analytical tools, new models and predictive approaches capable of capturing the rapidly changing structural setting of global forestry (Hurmekoski and Hetemäki 2013), and concepts from critical agrarian studies can help in addressing part of this lacuna. Flexing is also an overarching theme in which the recent revival of the forest industry in its traditional loci can be situated for analytical purposes. The flexible and multiple use of trees has increased significantly in recent years, a trend that is becoming ever more important to the future of the world's forestry, forests, and industrial and rural development. Meanwhile, new technology has brought a balance, and perhaps even a reversal, to the 2000s' development in which forestry capital flowed from North to South.

This contribution has taken account of the observation made by Lindahl and Westholm (2011) that major shifts in the global forest sector must be examined through analysis of its interplay with other sectors, an approach which should be strengthened in future by more explicit comparisons. In the crop sector, for example, flexing has led to a situation whereby different commodities, which previously had their own specific markets, have merged markets and now compete with a larger array of products: inter-sectoriality is thus a key issue for future studies.

Forestry practices influence the amount and type of flexing changes that can be introduced to its material basis, but so do new milling and other tree-processing applications (i.e. capital-generated processes that change technological prospects). I have argued that the rise of 'cheap trees', in the form of massive tree plantation expansion around the globe (Kröger 2014), has indirectly supported the creation of new flexing technologies, particularly in areas of the global North which import the 'cheap pulp': the pellets and other wood products that lower raw material costs and liberate their own forest areas for new uses.

While flexing might appear to boost differentiation by introducing an array of alternative end goods, the phenomenon actually seems to rely on creating globally uniform commodities at the rural level, thereby displacing the natural multiple-ness and flexible-ness of trees. In the past, many tree species were used for specific and different purposes while, in the current thrust, the goal for the biggest players would seem to be a few key tree species, flexed, which can be used for interchangeable and multiple purposes – preferably within the specific sub-path of flexing whose technologies of interchangeability each one controls. To facilitate the globalization of their markets, capitalists began by standardizing their commodities; now the market potential of these globally standardized goods is being maximized by flexing: two processes that correspond with Smith's (1984) classic notions of the opposite spatial tendencies of equalization and differentiation as the two basic premises of capitalist expansion.

From the viewpoint of agrarian political economy, the key reason for flexing is the increased power that it offers to those who are able to flex or de-multiply. As the global North typically cannot compete with the South in expanding the material basis due to the lengthy gap between harvests (the increased harvesting of stumps and branches being one of the only feasible responses), the North is competing by flexing the different uses of tree-derived commodities. The South, meanwhile, is reaping the benefits of scale via the option of plantations of patented and de-multiplied use (GM) trees, maximizing the control and production of a few bulk commodities, particularly pulp and wood energy (in the form of wood fuels and pellets). To this the North will inevitably respond by multiplying and flexing uses, creating new products with higher added value, and selling technologies to the South.

Different pathways of flexing are now taking root in different forestry regimes. The drive to expand low-lignin GM-tree monocultures in the global South – with lower flexible-ness and multiple-ness given that lignin is a key by-product on which processing phase flexing is based – suggests that a major rupture is evolving in the geopolitics of flexing, one driven by forestry practice and regime differences. Thus, I expect the future geography of flexing is likely to be divided into different trajectories along regionally specific lines, focusing on flexing pulp-based products (biofuels, energy, chemicals and plastics) in Finland and the pulp-producing regions of the global South (Brazil, Indonesia, Malaysia, Chile and Uruguay); and, to a larger extent, on construction and industrial wood products in timber-based/mixed (not paper-dominated) regions (Central Europe, North America, East Asia).

Flexible-ness and multiple-ness also signify an increase in the pressure to harvest forests. For example, the new biorefinery/pulp investments in Central Finland will need, between them, an extra 10 Mm³ of wood per year (current national harvests being 55 Mm³) (Tornberg 2015), and they are just two of myriad new forest biorefineries in the European pipeline.¹⁸ Flexing, therefore, is inevitably going to raise conflicts among different stakeholders.

There are also many risks in the option of deploying de-multiplying techniques in new tree-flexing operations: the negative socio-environmental impacts of TP and GM trees are one example; the problem of testing new technology (there have been fires in the recently inaugurated UPM biorefinery in Finland, for example) is another. The path of flexing is emerging as a rocky, risky and conflictive route as the impacts of this capitalist move become more visible.

Seen from a historical perspective, it seems to be the case that crisis creates and boosts flexing: trees have been used for many purposes that typically increase in such times, but research could be directed to whether this is a general tendency. While pine sap was used as a substitute for flour during the WWII food crisis in Finland, the current conjuncture is one of multiple global crises wherein climate disruption, over-accumulation of capital, depleting resources and decreasing profit rates are key vectors (Gills 2010). Furthermore, the reply to food shortage in WWII Finland did not comprise an example of capitalist flexing but was, rather, a subsistence or local/national livelihood-based, non-industrial scale version. The current flexing boom differs from prior flexible-ness and multipleness,

however, in being overtly capitalist, global and on an enormous industrial scale in consequence of differences in the nature of the current crisis: indeed, it is mostly a capitalist answer to a capitalist problem.¹⁹ Future research should thus study in greater detail the historical flexing of trees in relation to ecological crises, engaging in a comprehensive review of the literature and detailed empirical studies of how different trees, and their multiple parts and derived commodities (and by-/sub-products), are utilized globally, to verify the extent, key trajectories and dynamics of tree flexing suggested by this preliminary study.

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Footnotes:

¹New flex products can be merely stop-gaps – as with the example of pine sap substituting for wheat flour in WWII Finland – or even the figments of imagination. ‘Flexing narratives’ have been used to support speculation and outright scams based on exaggerated technological promises (Borrás et al.

2015), and it is essential to separate real advances from opportunistic advertising.

²In portfolio management, a beta of 1 signifies that an asset’s value has corresponded with the market average, and –1 signifies that it has been inverse to the market: a beta of 0 signifies there is no historical correlation.

³By ‘narrative flexing’, I refer to a pathway that uses both Borrás et al.’s (2015) ‘flex narratives’ (which do not depend on real, anticipated or imagined flexing, but can be used to legitimize a crop’s use by claiming that, for example, palm oil is going to be used for food, not biodiesel, although the contrary is true) and ‘imagined flexing’, ‘that is not real, not actually happening and has no material or logical basis, yet it is invoked for some reason’. I use the denotation here specifically for the case of ‘carbon capture’, which is a strong flex narrative, and can become real (in terms of capital accumulation) if ‘carbon credits’ are sold, but has no logical or material basis, as is discussed

below.

4This historical argument is a topic that future research should explore in detail. A fruitful approach would be to merge the agenda of world-ecology and the flex-crop framework.

5Future research should delve deeper into studying these hypotheses, and fine-tuning the rough categorization between 'North' and 'South' as ideal types.

6Calculation based on author's analysis of METLA (2015) databases.

7The few pulp companies of the global South that already have both fast-wood pine and eucalyptus plantations and experience in pulping them and turning them into paper products, such as Klabin in Brazil's Paraná state, are already initiating massive new pulp investments with both softwood and hardwood lines, alongside lines for special paper products (Brembatti 2015).

8For example, in Canada and other countries where not much thinning is carried out during growth, more lumber than fiber-wood is produced compared with the Scandinavian model (personal communication with Jakob Donner-Amnell, April 2014, Helsinki), which relies on thinning 2–3 times per growth cycle, yielding almost solely fiber and energy-wood; timber is harvested only at the end (together with further fiber and energy-wood).

9Author's elaboration based on METLA (2015) databases.

10Other flex-crops do not have this geographical disparity as their possible reach is more limited than that of trees: corn, soybean, sugarcane or palms, for example, cannot be grown on an industrial scale in the circumpolar regions.

11Leading companies' GM engineers (interviews by the author, Portugal and Brazil, 2008–2013) have tried to develop a flex-eucalypt that would serve an assortment of interchangeable purposes (thus overcoming the lignin dilemma), but these attempts have not been successful. The current trajectory of GM trees is one of de-multiplying tree uses, to strive for agrotoxic-resistant and more adaptable varieties that use larger quantities of water and soil nutrients, faster than their conventional counterparts (hybrids, etc.), and may thus have higher yields (but at large costs to the environment – so these are only short-term gains). The possibility of flex-tree variety development is still very much just a theoretical one based on the preliminary literature review and other data assessed here, which did not reveal GM trees to be more than a narrative flexing. However, future research should verify these assumptions.

12This is a biological option as trees are not annual crops requiring re-planting but, socio-politically, the reality might often be that human action is required; TPs in the global South, for example, are enclosed by violent methods and under the surveillance of their controllers (see e.g. Carrere and

Lohmann 1996; Kröger 2013b for this violence) while in Finland it is quite typical to find forest patches that were initially planted or semi-planted but left 'on their own' by the urbanized and conservation-minded family forest owner. These patches have become 'default non-flexing material basis', so long as the state/corporations do not force forest owners to stop their 'non-action' by demanding the forest be 'put into use' (in way they see fit) – an unlikely scenario under the new Finnish forest law which allows for greater leeway in forestry practices. These notes suggest the agency of both extra-human nature and those people in control of forest land in 'default' flexing.

13'Biomass-based value web' is a concept coined by Virchow et al. (2014), and is one basis for the flexing-approach – for Borrás et al. (2015, 8): "“Value web” emphasizes a continuous strategic flexibility in supply chains and ultimate products – by contrast to 'value chain', which implies rigid linear relationships'.

14But it is hard to make any global prognosis, as the markets for car fuel are likely to be confusing for some years to come, with many alternatives (ethanol, methanol, biodiesel, biogas, electricity, hybrid, etc.) competing – only time will tell which of these will dominate (Jokinen, Mononen, and Sairinen 2011).

15Tall oil is sold to chemical-industry paint makers as resin, and companies relying on the supply are unhappy about now having to compete for an essential material for which they have no alternative source.

16Author's calculation based on METLA (2015) data.

17Pressured by the paper industry, the government curbed its incentive policy for heating wood, lowering the diameter of trees eligible for subsidies, so as to reserve small trees for pulp-making; such legislative moves can have major impacts on flexing pathways.

18According to Näyhä et al. (2014, 45), in 2013 there were 23 lignocellulosic, biomass-based biorefineries in operation or being built in Europe, but most of these were pilot or demonstration plants.

19Paradoxically, capitalistic competition that makes it difficult to share profits among biorefinery consortium members (to be viable, a large consortium of actors with differing skills is necessary to make flexing a reality) is a major obstacle to flexing expansion (see Näyhä and Pesonen 2014).

Figure 1. Parts of the trees used by heating power plants in Finland, 2000–2013.

Figure 2. This figure illustrates how the new bio-product mill will increase tree-derived commodity flexing in several ways (source: reproduced with permission from MetsäFibre [2015](http://www.metsafibre.com) MetsäFibre. 2015. Äänekoski bioproduct mill. April 21. www.metsafibre.com).

Table 1. Examples of tree-flexing and multiple-use changing pathways.

Type of flexing-change	New technological possibilities increasing real and anticipated flexible-ness				'Narrative flexing' based on new commoditization	De-multiplying the material basis use possibilities
Key examples of flexing and multiple-use changing applications	Wood-based energy		Pulp, paper, cardboard and timber products replacing fossil fuels		'Carbon sinks'	Fast-growth, low-lignin content GM (genetically modified) trees
Methods of flexing and multiple use-change	(1) Biofuels	(2) Electricity and heating	(3) Lumber (sawnwood)	(4) Fiber-wood	'Carbon capture'-calculation narratives	Expanding GM tree plantations
Key product examples	Second-generation wood-based biodiesel, ethanol, oil and gas	Wood chips and pellets	Veneer; new construction materials (e.g. wood-plastic composites); industrial materials (e.g. cross-laminated timber)	Pulp; bioplastics; pulp-based textiles replacing polyester; biochemicals in medicines, paints, foods; feed	Carbon credits (REDD - reducing emissions from deforestation and degradation, CDM - Clean Development Mechanism etc. schemes); 'carbon storage'	Hardwood bleached paper pulp and solid-wood biofuel from e.g. GM eucalyptus and poplar
Examples of some key forestry companies	UPM and Fibria (wood-fuels), Metsä-Fibre (wood-gas)	German Pellets, Enviva	West Fraser Timber, Weyerhaeuser, Stora Enso	UPM, Stora Enso	Plantar (CDM)	Suzano (FuturaGene)
Inter-industry merging with (and examples of companies linking up), and new players	Chevron, Shell, Fortum (energy), Metso (machinery), Envergent Technologies (oil technology), UOP Honeywell (detergent)	Coal and other power plants	Construction industry, automobile industry, furniture industry, nanotechnology	Chemical and pharmaceutical industry, automobile industry, textile producers	Steel industry (TP - tree plantation emission compensation schemes, charcoal production)	Glyphosate and fertilizer producers, GM companies

Table 1. Examples of tree-flexing and multiple-use changing pathways.

Type of flexing-change	New technological possibilities increasing real and anticipated flexible-ness	'Narrative flexing' based on new commoditization	De-multiplying the material basis use possibilities
	technology), Ensyn (energy and chemicals), BillerudKorsnäs (packaging)		

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