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Engineering Living Infrastructures: The Biopolitical Economy of Poplar Architectures in the Anthropocene

Ingegneria delle infrastrutture viventi: l'economia biopolitica delle architetture di pioppo nell'Antropocene

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ABSTRACT

The article investigates the growing role played by «living infrastructures» in the Anthropocene. In particular, it investigates the complex biopolitical economy underlying the infrastructuralisation of the poplar tree – a botanical genus, whose metabolism is increasingly mobilised in public and private initiatives aimed at fighting desertification, environmental toxicity and climate change. Focusing on the ongoing expansion of poplar plantations, it discusses the integration of living infrastructures into financial markets and carbon credit schemes and interrogates the new frontiers of capital accumulation opened by the molecular engineering of living infrastructures.

KEYWORDS: Living Infrastructures; Biopolitical Economy; Forests; Carbon Plantations; Carbon Markets.

Nel contesto della presente crisi climatica ed ambientale, istituzioni pubbliche e private promuovono la costruzione di 'infrastrutture viventi'. L'articolo analizza l'economia biopolitica che caratterizza questi progetti, concentrandosi sull'infrastrutturalizzazione del pioppo: un genus botanico ampiamente utilizzato come 'barriera contro la desertificazione', 'struttura di fitorisanamento', e 'pozzo di assorbimento di anidride carbonica'. Questi progetti mobilizzano il metabolismo della cellula vivente, dando forma a nuove reti di potere bio-infrastrutturale ed elaborate strategie di accumulazione del capitale.

PAROLE CHIAVE: Infrastrutture Viventi; Economia Biopolitica; Foreste; Piantagioni del carbonio; Mercati del carbonio.

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Confronted by a planetary ecological crisis that increasingly threatens the infrastructural networks that sustain human life and industrial activity, living organisms are increasingly mobilised in the construction of new forms of «natural», «green», «biotic», «ecological» and «living» infrastructures. Oyster life cycles are channelled towards the construction of artificial urban reefs, the metabolism of black soldier flies is directed to digest urban waste, the photosynthetic capacity of trees and shrubs is harnessed in carbon capture and storage initiatives. In the first part, we discuss the infrastructuralisation of living organisms in the context of a crisis of high-modernist ideals, which stimulates new conceptions of modernity, spatial politics as well as sovereign authority in the so-called Anthropocene epoch. Modernist infrastructures contributed to carving global geographies, forge planetary logistical chains and institute a world wide web shaped by the endless circulation of bodies, commodities and coded information; ecological infrastructures seek to remediate and techno-fix some of the noxious effects of this «Great Industrial Acceleration» on a planetary scale. While critical studies of infrastructure abound, and analysis on «ecological» and «living» infrastructures have recently emerged, the multiple labour practices through which living organisms are socially (re)constructed as infrastructure have received less attention.

To contribute to this analysis, part two emphasises the complex biopolitical economy that enables the social construction of poplar trees as promissory living infrastructures for the Anthropocene: a botanical *genus* increasingly mobilised in public and private initiatives aimed at fighting desertification, water pollution and atmospheric CO_2 concentrations. First, we consider the role played by poplar plantations in ongoing efforts to build a «Great Green Wall» in Northern China: a living infrastructure designed to halt the ongoing expansion of the Gobi Desert. Second, we reflect on the cultivation of poplar forests designed as phytoremediation infrastructures. To make poplars live – as a biotic barrier or as a living bio-technical apparatus for environmental remediation – public and private projects must mobilise different forms of biopolitical labour at multiple scales, from the molecular to the planetary. They must also interact with existing infrastructural environments in a multiplicity of complex and contradictory ways.

In the third part, we continue this analysis by focusing on the integration of living infrastructures in financial markets. Focusing on the recent commercialisation of carbon credits produced by gene-edited «climate-smart» poplars developed by the biotech platform company Living Carbon, we discuss some of the new frontiers of capital accumulation opened by the molecular engineering of living infrastructures in the Anthropocene. Newly emerging GM forests are molecularly designed to operate as a living «carbon sink» for the Anthropocene, but also as a source of carbon credits to be traded in specialised financial markets. Guided by the financial incentives provided by carbon finance, biotech companies are turning the poplar tree

into a bio-technical infrastructure, whose metabolic activities are purposefully designed to accelerate its growth and increase its carbon capturing capacities. The complex histories of monocrop plantations, carbon trading and genetic engineering intertwine in the arboreal root systems of these living infrastructures, opening up a number of questions concerning the convergence of biopower and infrastructural power in the Anthropocene.

1. The Redemptive Futurity of Living Infrastructures

Since the nineteenth century, an ever-more complex web of roads, railways, airports, oil pipelines, shipping lanes, fibre-optic cables, tunnels, aqueducts, gas networks, and electrical systems sustains and supports modern life. Built above, through and below the ground, infrastructural systems constitute fundamental and foundational sociotechnical assemblages of modern societies: a series of installations that shape both biological and social life[1]. In the last twenty years, an «infrastructural turn» in the social sciences has brought increasing attention towards the *social* life of these technical systems[2]. Critical studies of infrastructure have brought about a methodological inversion by which infrastructures – traditionally treated as a neutral technical ground on which social and political activities take place – become complex and contradictory political entities to be deconstructed and systematically studied in their social context.

In this way, infrastructural analysis has contributed to bring the invisibilised and naturalised eco-technical background that sustains social life into the foreground[3]. Infrastructures function as platforms that enable people and things to move, converge and operate conjunctively promoting «an anticipatory state around which different subjects gather their promises and aspirations»[4]. In this sense, infrastructures continue to be «always about the future»[5]. Yet, with the recent recognition that planet Earth has entered a new geological era, the future is no longer the same: it is increasingly splintered in multiple divergent futures that coexist, interact and recombine in an increasingly contradictory present. The futures conjured by post-Fordist, techno-financial optimism now exist in uncomfortable imbrications with dystopian visions of impending socioecological doom.

[1] L. KANOI ET AL., *'What is Infrastructure? What does it do?': Anthropological Perspectives on the Workings of Infrastructure(s)*, «Environmental Research: Infrastructure and Sustainability», 2, 1/2022, 012002.
[2] For a review of this literature, see: N. ANAND – A. GUPTA – H. APPEL (eds), *The Promise of Infrastructure*, Durham, Duke University Press, 2004. For a more focused review of infrastructural nature, see: S. NELSON – P. BIGGER, *Infrastructural Nature*, «Progress in Human Geography», 46, 1/2022, pp. 86-107.
[3] B. LARKIN, *The Politics and Poetics of Infrastructure*, «Annual Review of Anthropology», 42, 1/2013, pp. 327–43.
[4] K. HETHERINGTON, *Surveying the Future Perfect: Anthropology, Development and the Promise of Infrastructure*, in P. HARVEY ET AL. (eds), *Infrastructures and Social Complexity*, London, Routledge, 2019, pp. 58-68.
[5] J. CAMPBELL, *Nature, Infrastructure, and the State: Rethinking Development in Latin America*, «The Journal of Latin American and Caribbean Anthropology», 19, 2/2015, p. 193.

From the point of view proposed by eco-modernist Earth-system scientists such as Anthony Barnosky, global politics in the Anthropocene is faced by «widespread disruptions in natural landscapes and societal functions». It must, therefore, focus on «maintaining life support systems» by mobilising «the same things that worked successfully in dealing with past global crises», including «technological advances» and «new infrastructure». The framing of the ecological crisis in terms of a collapse of «life-support systems» is indicative of an emergent epistemology that grasps and converts the entire Earth's biosphere as a planetary infrastructure for industrial society. The rapid construction of military-industrial infrastructures after World War II - although intimately implicated in the developmental model leading to the current planetary crisis - is now presented as a positive model to conceive and implement a new, green infrastructural effort. «In just 7 years,» write the authors of *Scientific Consensus on Maintaining Humanity's Life Support Systems in the 21st Century*, «the USA built its airplane fleet from about 3,100 to 300,000 planes, and beginning in the 1950s, took less than 50 years to build 47,000 miles of interstate highways – enough paved roads to encircle Earth almost twice». Readjusting this model to the present conjuncture, global politics must now focus on «investing in vital 'green infrastructure', such as through restoring wetlands, oyster reefs, and forests»[6].

In line with this urgent call, a new wave of «nature-based», «green», «ecological» and «biotic» infrastructural projects are presented by states and corporations as providing a bio-technical solution to control and govern rapidly proliferating ecological crises. In conversation with existing critical literature on infrastructures, and on infrastructural natures, we ask: If social studies of infrastructures have shown that modern life is defined by its embeddedness in complex infrastructural systems, what does this analysis entail when living bodies are themselves turned into building blocks for the construction of critical biotic infrastructures? How are living organisms being socially reconstructed into infrastructural systems? What discursive and material processes underlie this process of infrastructuralisation of life? How is the metabolism of the living cell being mobilised in order to pursue multiple political projects and corporate ventures? What social relations are reified in the

[6] A. BARNOSKY ET AL., *Introducing the Scientific Consensus on Maintaining Humanity's Life Support Systems in the 21st Century: Information for Policy Makers*, «The Anthropocene Review», 1, 1/2014, pp. 78-109. See also: W. STEFFEN ET AL., *The Trajectory of the Anthropocene: the Great Acceleration*, «The Anthropocene Review», 2, 1/2015, pp. 81-98. Here, and throughout the article, we are interested in analysing – and partially deconstructing – dominant narratives of the Anthropocene. We, thus, refer to this concept to indicate both the current geological epoch – increasingly characterised by rapid and unpredictable ecological transformations, biodiversity collapse and climate change – and dominant interpretations of it. We emphasise that this very concept risk systematically obscuring the role of capital markets, colonial domination and gendered violence in the global processes that, since the nineteenth century, have introduced dramatic changes to Earth's biogeochemistry. See for instance: A. MALM – A. HORNBORG, *The Geology of Mankind?*, «The Anthropocene Review», 1, 1/2014, pp. 62–69; and D. HARAWAY, *Anthropocene, Capitalocene, Plantationocene, Chthulucene: Making Kin*, «Environmental Humanities», 6, 1/2015, pp. 159-165.

infrastructuralisation of living organisms? What ontologies of 'nature' and 'society' run through infrastructuralised oyster reefs, ant colonies and poplar forests?

Both discursive and material shifts contribute to the infrastructuralisation of living ecosystems. The ascent of concepts such as «natural infrastructure» – both in social theory and in public policy discourse – is associated with an extension of calculative reason and the «modernist desire to render social and environmental heterogeneity manageable and amenable to standardised solutions»[7]. As Sarah Nelson and Patrick Bigger point out, extending this calculative reason to render ecosystems «investable as infrastructure for sustaining capitalist (re)production» requires a significant epistemic work with inherently «biopolitical, territorial, and futurological dimensions», which allow for the social construction of «continuities with other kinds of infrastructure investment»[8]. The conceptual conversion of living ecosystems into critical infrastructures for the reproduction of social life is conducive to growing bio-technical interventions, and the application of management techniques geared towards their maintenance and functional rationalisation. Already in the early 1980s, for instance, wetlands have been integrated into many cities plans as a green infrastructure for the management of urban stormwater runoff, leading to increasing conservation efforts, governance initiatives and engineering interventions to maximise their absorption capacity[9].

Similarly, in the 1990s the UN Food and Agriculture Organization (FAO) invited states to reconceive «forests as infrastructures», since «forests provide infrastructural services without which development opportunities decline. They stabilise stream flow and microclimates, protect land and earth structures such as roads and canals, drain and shade the land, and purify the atmosphere»[10]. From the functionalist point of view promoted by FAO, «urban trees cool towns, conserve energy and absorb pollutants substituting for more conventional infrastructure, which would otherwise be soon needed»[11]. Forest ecosystems are reframed as service-providing infrastructures equivalent to – and potentially substitutable by – built infrastructures such as air-conditioning systems and windbreakers. The infrastructural gaze, in other words, renders ecosystems into purely instrumental service providers, whose utility can be measured through calculative reason: their functional value can be quantitatively appraised since «the absence of forests clearly requires constructed

[7] A. CARSE, *Nature as Infrastructure: Making and Managing the Panama Canal Watershed*, «Social Studies of Science», 42, 4/2012, pp. 539–63.
[8] S. NELSON – P. BIGGER, *Infrastructural Nature*, «Progress in Human Geography», 46, 1/2022, pp. 86-107.
[9] A. STEFANAKIS, *The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management*, «Sustainability», 11, 24/2019, 6981.
[10] FAO, *State of the World's Forests*, Ginevra, FAO Publishing, 1995, pp. 15-18.
[11] This is a quintessentially neoclassical economist view of 'nature'; environmental economist Robert Solow argued that «if it is very easy to substitute other factors for natural resources, then there is in principle no 'problem'»; resources, include in this case, the ability to 'sink' carbon. R. SOLOW, *The Economics of Resources or the Resources of Economics*, in C. GOPALAKRISHNAN (ed), *Classic Papers in Natural Resource Economics*, London, Palgrave, 1974, pp. 257-276.

infrastructure at the expense of other potential uses of scarce capital». It is exactly in this way that, according to FAO, forests «are entering the central equations of macro-economic growth». If they are maintained, it is only insofar as they are «widely acknowledged as both productive capital stocks and as component of public infrastructural systems»[12].

The infrastructural conception of ecosystems is now presented matter-of-factly in conservation documents, engineering projects and legislative proposals[13]. For instance, an Assembly Bill recently introduced in the state of California holds that «source watersheds are recognised and defined as integral components of California's water infrastructure». Forests, meadows, streams and rivers are thus rendered – together with pipes, treatment plants and reservoirs – part of an eco-infrastructural assemblage regulating water flows. Once riverine ecosystems are re-fashioned as supporting infrastructure for the channelling of water sources, activities such as «upland vegetation management» and «meadow restoration» along riverbanks become eligible for the same kind of financing as the building of more conventional infrastructure. The California Assembly Bill, for instance, enables public institutions to offer financial incentives to landowners for the «conservation of private forests to preserve watershed integrity through permanent prevention of land use conversion».[14] Infrastructuralisation and financialisation go hand in hand: as privately-owned ecosystems are re-conceptualised as functional infrastructures providing essential services to the public, new financial incentives are offered to landowners for their conservation.

This can be understood as a structural tendency inherent to capital accumulation in the so-called Anthropocene. The infrastructural reconfiguration of living ecosystems enables landowners to capture new forms of rent through a whole variety of emerging financial instruments such as carbon credits and conservation easements.[15] Shifts in discourse, policy, and material practice re-construct living ecosystems as critical infrastructures. Financial incentives aim to steer public and private actors not only to conserve these biotic infrastructures, but also actively engineer them into existence. Increasingly, a range of ecological engineering projects aspire to 'harness', 'direct' and 'engineer' the bodily metabolism of living organisms to provide various ecosystem services.

Black soldier flies are reared to metabolise municipal waste as part of Guangzhou's urban infrastructure.[16] Goats are turned into «a wildfire prevention tool» as

[12] FAO, *State of the World's Forests*, p. 18.
[13] S. NELSON – P. BIGGER, *Infrastructural Nature*, pp. 86-107.
[14] CALIFORNIA ASSEMBLY, *Source Watershed: Financing (AB-2480)*, leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill_id=201520160AB2480, accessed 15 November 2023.
[15] T. PURCELL – A. LOFTUS – H. MARCH, *Value – Rent – Finance*, «Progress in Human Geography», 44, 3/2020, pp. 437-456. See also: J. CHRISTIANSEN, *Securing the Sea: Ecosystem-based Adaptation and the Biopolitics of Insuring Nature's Rents*, «Journal of Political Ecology», 28, 1/2021, pp. 337-357.
[16] A. ZHANG, *Circularity and Enclosures: Metabolizing Waste with the Black Soldier Fly*, «Cultural Anthropology», 35, 1/2020, pp. 74–103.

part of a Life Project sponsored by the EU's Infrastructure and Environment Executive Agency[17]. Llamas are introduced in the territory surrounding Chicago airport to transform the landscape, displacing «wildlife that may be hazardous to airport operations».[18] Most recently, the State of New York has begun constructing 2400 linear feet of «Living Breakwaters» as a critical infrastructure to govern rising seas and floods. The $107 million project mobilises oysters' metabolic processes and gregarious behaviour to adapt urban coastlines to a changing climate. In its promotional material, the private firm implementing the project presents these oyster reefs as an exemplary case of their «hybrid eco-infrastructural approach» to build «climate-adaptive green infrastructures»[19]. Similarly, Canberra has launched a «Living Infrastructure Plan», which strives to reduce «the risks from the key climate change impacts of heatwaves, droughts, storms and bushfires, through resilient living infrastructures» such as urban forests and green canopy[20]. Rather than being flaunted as symbols of futurism, modernity and progress, Canberra's «living infrastructures» and New York's «living breakwaters» are sponsored as a last line of defence against a looming future of global warming, rising sea levels and toxic pollution.

In this sense, these living infrastructures are infrastructures *of* and *for* the Anthropocene. As such, they reify the shifting notions of politics, geography and temporality that characterise the present conjuncture. If the most symbolic infrastructures of high-modernity – high-speed railways, paved roads and electric cable wires – work towards imagined futures of industrial comfort and logistical speed, living infrastructures are mostly designed to ward off a future increasingly imagined as a time of environmental collapse. In a scorching political climate, biopower and infrastructural power converge in the infrastructuralisation of living bodies. The bodily metabolism of living organisms – bacteria, plants and animals – is directly mobilised in state planning. It becomes an instrument of government, a soothing eco-technical fix and a fount of political legitimacy. Living infrastructures, in other words, represent a relatively new instantiation of what Michael Mann has called «infrastructural power»: biotic tools of governments through which «political elites can extract resources from, and provide services to, all subjects»[21].

The role of the infrastructural state, however, is no longer imagined in messianic terms as having as its fundamental goal to accelerate historical time to reach an

[17] R. LOVREGLIO ET AL., *Goat Grazing as a Wildfire Prevention Tool*, «iForest: Biogeosciences and Forestry», 7, 4/2014, pp. 260-268.
[18] M. OBERMAN, *Llamas and Goats Keep Grass Cut at Chicago Airport*, «Phys», https://phys.org/news/2013-08-llamas-goats-grass-chicago-airport.html, accessed 15 November 2023.
[19] K. ORFF, *Shellfish as Living Infrastructures*, «Ecological Restoration», 31, 3/2013, pp. 317-322; S. WAKEFIELD, *Making Nature into Infrastructure: The Construction of Oysters as a Risk Management Solution in New York City*, «Environment and Planning E: Nature and Space», 3, 3/2020, pp. 761-785.
[20] AUSTRALIAN CAPITAL TERRITORY GOVERNMENT, *Canberra's Living Infrastructure Plan: Cooling the City*, «Environment Act», www.environment.act.gov.au, accessed 15 November 2023.
[21] M. MANN, *Infrastructural Power Revisited*, «Studies in Comparative International Development», 43, 3/2008, pp. 355–365.

Utopian future; rather, it is performing a political work of endless deferral, indefinitely postponing ecological catastrophe[22]. In this sense, we may say that the political theology underlying the construction of such infrastructures is dominated by the figure of the *katechon*: a force that perpetually holds back and resists the unfolding of time and the coming catastrophe[23]. As Donna Haraway points out, «secular salvation history depends on the power of images and the temporality of ultimate threats and promises to contain the heteroglossia and flux of events»[24]. Today, these salvation narratives, with their religious overtones, are secularised not only in political discourses but also in the sober statements of infrastructural engineering projects, where they infuse both promise of progress and threat of apocalypse. Engineered oyster reefs and urban forests are often presented as paradigmatic materialisations of a providential postmodern turn away from anthropocentrism and towards innovative forms of «interspecies collaboration» promoting «spatial modes of kinship with non-humans in the crafting of more sustainable built environments» and «other than human solutions» to socio-ecological issues[25].

What is radically obscured in such political theology – and, to some extent, Haraway's critique of it – is how living infrastructures are intimately connected to the uneven unfolding of climate change and «histories of colonial oppression, exclusion and racialization». In an important contribution, Keston Perry and Leon Sealy-Huggins have argued that the push within the UN by Global North countries for green technology fixes to racial capitalism's «eco-imperial crisis» constitutes a form of «white redemptive power», which increasingly adds «credence to the rational redemption of the state as a basis for socio-ecological transformation»[26]. In the next section, extending our analysis to UN sponsored programs promoting plantation forestry across the world, we consider how this redemption of the state is materially pursued through the social re-construction of poplar plantations into living infrastructures promoted as bio-technical fixes set to repair metabolic rifts and hold back climate change.

2. The Biopolitical Economy of Poplar Infrastructures

Engineering living infrastructures – while often idyllically presented as an effortless 'harnessing' of life's metabolic power – must be analysed as a gigantic labour

[22] D. ROTHE, *Governing the End Times? Planet Politics and the Secular Eschatology of the Anthropocene*, «Millennium», 48, 2/2020, pp. 143-164.
[23] E. BORG – A. POLICANTE, *Mutant Ecologies: Manufacturing Life in the Age of Genomic Capital*, London, Pluto Press, 2022; G. AGAMBEN, *The Time that Remains: A Commentary on the Letter to the Romans*, Redwood, Stanford University Press, 2005, p. 110.
[24] D. HARAWAY, *Modest_Witness@Second_Millennium. FemaleMan©_Meets_OncoMouse™. Feminism and Technoscience*, London, Routledge, 1996, p. 10.
[25] V. MEILLER, *Animal Infrastructures: Building Across Species*, «The Architectural Review», https://www.architectural-review.com/essays/keynote/animal-infrastructures-building-across-species, accessed 15 November 2023.
[26] K. PERRY – L. SEALEY-HUGGIN, *Racial Capitalism and Climate Justice: White Redemptive Power and the Uneven Geographies of Eco-imperial Crisis*, «Geoforum», 26, 2/2023, 103772.

process which presupposes capital investments, public interventions, and active human effort. In this section, we focus on the different kinds of biopolitical labour that are currently mobilised to socially (re-)produce the poplar tree as an eco-technical apparatus for fighting desertification, water pollution, and rising greenhouse gas concentrations. Focusing on long-standing projects supported by the International Poplar Commission (IPC), we analyse the infrastructuralisation of the poplar as part of the historical and geographical construction of a global biopolitical economy: a strategy of accumulation and a mode of government, increasingly reliant on the development of a technoscientific knowledge of biological processes and new means of manipulating them[27].

Since the 1940s, poplar plantations have rapidly expanded, apace with larger socio-economic processes of modernisation, industrialisation and globalisation. Today, they are present in over thirty countries, covering over 15 million hectares. The exponential growth of poplar plantations is often explained as a consequence of its botanical characteristics: «poplars are some of the fastest growing trees», write a group of biologists commissioned to report on the state of the global poplar industry, «foresters have sought to capitalise on this potential at least since the 1940s»[28]. In fact, the parallel historical processes of *ecological expansion* and *industrial subsumption* of poplar trees have been shaped not only by the technical labour of specialised foresters, but also by a complex entanglement of interposing entities, including: poplar hybrids and clones, desert storms and insects; but also environmental activists, state diplomats, international institutions and financial markets. The global history of poplar forestry, in other words, is a constitutive articulation of the eco-political history of the Anthropocene.

In 1947, the establishment of the International Poplar Commission (IPC) – one of the first technical statutory bodies created within the framework of the Food and Agriculture Organization of the United Nations (FAO) – institutionalised a global program devoted to the systematic promotion of plantation forestry and, more specifically, of poplar silviculture as «a priority to supporting reconstruction of rural and industrial economies»[29]. The *populus* was presented as a most promising *genus* – comprising over 30 botanical species – for advancing global industrialisation and supporting the expansion of scientific, mechanised forestry around the world. Poplars' capacity to grow rapidly, establish resilient colonies in arid environments and support industrialisation appeared – at least to state agriculturalists – symbiotic with modernist aspirations[30]. In the 1950s and 1960s, the IPC contributed to the

[27] E. BORG – A. POLICANTE, *Mutant Ecologies*, pp. 7-22.
[28] J. STANTURF ET AL., *Ecology and Silviculture of Poplar Plantations*, in D. DICKMANN ET AL., *Poplar Culture in North America*, NRC Publishing, 2021, pp. 153-206.
[29] INTERNATIONAL POPLAR COMMISSION, *Poplars in Forestry and Land Use,* Rome, FAO Publishing, 1958.
[30] R. RAFFAETÀ, *Tutti i colori del verde. Il ruolo del verde urbano nei processi di cittadinanza nella città di Bolzano*, «Archivio antropologico mediterraneo», 21, 1/2019, pp. 1-19.

establishment of poplar plantations in India, Brazil, Chile, South Africa and China with the aim of scaling up the production of lumber, pulp and other raw materials for the booming global marketplace.

In the 1970s, the international organisation gradually shifted its focus towards a more complex and multifaceted conception of poplar plantations, supporting forestry programs «with a view to sustaining livelihoods, land uses, rural development and the environment». The second edition of the IPC manual, published in 1979, while retaining chapters providing guidance for the establishment of plantations for wood and fibre production, included chapters promoting planted poplars for «enhancing landscapes», «resisting desertification» and «regenerating the atmosphere»[31]. Since then, through a variety of public and private projects, poplar plantations have been socially re-constructed into flexible, eco-technical infrastructures designed to address a variety of socio-ecological issues from desertification to heavy-metal pollution, landfill reclamation, wastewater treatment and climate change.

Implementing a prolonged public program of afforestation, China now accounts for over 73 percent of the world's total poplar plantation area. This expanding plantation ecology is mostly geared towards the production of raw materials such as wood and pulp to be then transformed in a multiplicity of commodities. The Three-North Shelterbelt Forest Program, however, represents a paradigmatic case of plantation forestry geared towards the provision of various ecosystem services. Launched in 1978, with support by the FAO and the IPC, this colossal program of afforestation strives to halt the ongoing expansion of the Gobi Desert by erecting a «Great Green Wall», in the form of a national network of planted forests spanning 35 million acres of trees. This dense forest web has been designed to act as a windbreaker to help stabilise the soil, contain dust storms and green arid landscapes: a silvicultural infrastructure aimed at creating an enabling environment for human life and labour. The program has been hailed as an exemplary success of international programs of «transfer of germplasm, scientific knowledge and technology» by which the International Poplar Commission encouraged the importation into China of high-performing, fast-growing poplar clones of the I-214 variety originally developed by the Poplar Research Institute of Casale Monferrato in the 1930s. This inaugurated a stable collaboration between Italian and Chinese research centres, which continued throughout the 1970s and 1980s with regular shipments of poplar clones to be nursed, tested and planted in China[32].

Following this line of experimentation, China's State Forestry Administration has increasingly focused on the cultivation of the three hybrid poplars – *Populus*

[31] INTERNATIONAL POPLAR COMMISSION, *Poplars and Willows in Wood Production and Land Use*, Rome, FAO Publishing, 1979.
[32] FAO, *Growing Poplars for Food Security*, «FAO», https://www.fao.org/newsroom/detail/Growing-poplars-for-food-security/en, accessed 15 November 2023. See also: R. MELI, *La Certificazione del Pioppo in Italia*, «Agricoltura Ricerca», 6, 22/1983, pp. 56-59.

simonii, *Populus szechuanica*, and *Populus pyramidalis bolleana* – that currently make up over 60 percent of this public, green infrastructure[33]. These varieties have been chosen on the basis of their botanical characteristics: a thick root system to bind the soil together, dense foliage to reduce wind speed, regular dissemination of leaves and twigs to aliment the soil. As most poplar hybrids, these cultivars are easily cloned through vegetative propagation, facilitating the job of establishing homogeneous plantations – most often composed of genetically identical trees. The clones are obtained by hardwood stem cuttings, a labour-intensive form of reproduction by which workers can «multiply a single mother plant quickly into thousands of identical plants». In the early spring, workers prune woody shoots from existing trees and plant them into the soil. These «poplar sticks» quickly produce roots and «grow from 1 to 4 metres tall in the first growing season, depending on genotype and local environmental conditions». Herbicides, notably glyphosate and 2,4-dimethylamine, are widely applied during early growth to limit competing weeds[34].

Poplar plantations can be arranged in a variety of geometrical patterns, depending on the socio-ecological function they are to perform. Industrial poplar plantations – designed for wood production and mechanised harvesting – tend to follow a geometrical scheme known as «mosaic of monoclonal blocks»: hundreds of identical clones are planted next to each other to form genetically homogenous blocks of one to five acres, with each block being composed of a set of clones obtained from a different «mother tree»[35]. Different geometrical patterns shape the «windbreaker structures» that compose the Great Green Wall: poplars are planted in «multi-layered shelter belts» composed of a «primary tree belt» – made of at least six rows of poplars – and multiple, smaller «secondary tree belts»[36]. By planting trees in carefully planned *biopolitical geometries*, forestry agencies not only make poplars live; they make them grow in predisposed patterns, thereby shaping poplars into living structures that direct wind and water flows, stabilise soil movement, and keep sand dunes at bay.

As confirmed by recently published satellite records, net forest coverage across the country has grown from 115 million hectares in 1981 to 220 million in 2020[37]. Decades of biopolitical labour – a form of labour aimed at sustaining, shaping and

[33] M. LI ET AL., *An Overview of the "Three-North" Shelterbelt Project in China*, «Forestry Studies in China», 14, 1/2012, pp. 70-79. See also: J. ZHAI ET AL., *Assessing the Effects of China's Three-North Shelter Forest Program over 40 years*, «Science of The Total Environment», 857, 1/2023, 159354.

[34] INTERNATIONAL POPLAR COMMISSION, *Poplars and Willows: Trees for Society and the Environment*, Rome, FAO Publishing, 2014, pp. 186-191, p. 38. See also: F. ARCHAUX ET AL., *Towards Practices Favourable to Plant Diversity in Hybrid Poplar Plantations*, «Forest Ecology and Management», 259, 12/2010, pp. 2410-2417.

[35] R. BURDON – J. AIMERS-HALLIDAY, *Managing Risk in Clonal Forestry*, «CABI Reviews», 9, 1/2016, pp. 33-47.

[36] INTERNATIONAL POPLAR COMMISSION, *Poplars and Willows*, pp. 259-262.

[37] J. ZINDA ET AL., *China's Summons for Environmental Sociology*, «Current Sociology», 66, 6/2018, pp. 867–885. See also: J. ZINDA ET AL., *Dual Function Forests in the Returning Farmland to Forest Program and the Flexibility of Environmental Policy in China*, «Geoforum», 78, 1/2017, pp. 119–132.

controlling the metabolic processes characterising living organisms – contributed to construct a living barrier against the advancing desert; a bio-technical infrastructure, whose metabolism has modified the biogeochemical composition of the atmosphere[38]. According to China's National Forestry and Grassland Administration, this network of planted forests stores over 9 billion tons of carbon and its yearly growth translates into roughly 700 million tons of sunk carbon[39]. This colossal, biopolitical labour of «forest building» (造林) is central to China's response to the global ecological crisis and its emergent aspiration to «construct an Ecological Civilization» (生态文明)[40]. According to Xi Jinping's statement to the 19th Congress of the Chinese Communist Party, the introduction of this new guiding principle, inscribed in the 2018 Chinese constitution, «seeks a kind of modernization that promotes harmonious symbiosis of Man and Nature»[41]. The «construction of an ecological civilization», in other words, promotes thinking of ecosystems as «a type of infrastructure to be engineered alongside the built environment»[42].

The expansion of forest plantations has been hailed as the primary embodiment of this political shift towards the construction of living infrastructures for the Anthropocene. Yet, government-led afforestation programs have not been without their biological accidents, unexpected ecological issues and political controversies. In the first half of the 1980s, the longhorn beetle seriously damaged the Great Green Wall, causing widespread poplar mortality and triggering debates on the risks inherent to industrial monocultures. In 2000, a new infestation caused the demise of over one billion poplar trees. Scientists have attributed the recurrent epidemics to the limited number of poplar varieties used, and the genetic uniformity of the clones. Critical geographers such as Hong Jiang maintain that the building of the Great Green Wall has eventually led to the establishment of «green deserts»: noting that poplar monocultures «help increase the government figure in trees», yet «fail

[38] This definition of biopolitical labour represents an elaboration of Foucault's classic definition of biopolitics as «a power that exerts a positive influence on life, that endeavours to administer, optimise, and multiply it, subjecting it to precise controls and comprehensive regulations». Elaborating on this perspective, we conceptualise 'biopolitical labour' as encompassing multiple labouring activities geared towards administering, governing and manipulating the life processes of living organisms. It is, therefore, rather different from alternative formulations of the same concept as found, for example, in Michael Hardt Antonio Negri's writings. See: M. FOUCAULT, *The History of Sexuality, Volume 1*, London, Penguin, 1998, p. 137; M. HARDT – A. NEGRI, *Commonwealth*, Cambridge, Harvard University Press, pp. 141-143; and E. BORG – A. POLICANTE, *Mutant Ecologies,* pp. 92, 259-263.

[39] F. WEI ET AL., *Ecological Civilization: China's Effort to Build a Shared Future for all Life on Earth*, «National Science Review», 8, 7/2021, nwaa279. See also: C. CHEN ET AL., *China and India Lead in Greening of the World through Land-use Management*, «Nature sustainability», 2, 2/2019, pp. 122-129.

[40] The fundamental principles guiding the construction of a future ecological civilisation have been detailed in two official documents published in 2015 by the Central Committee of the CPC: *Views on Speeding up the Promotion of Building the Ecological Civilization* and *The General Scheme of the Institutional Reform for Ecological Civilization*. See: G. SHEN, *Ecological Conservation, Remediation and Construction for Building an Ecological Civilization in China: Concepts for Ecological Activity*, «Frontiers of Agricultural Science and Engineering», 4, 4/2017, pp. 376-379; and F. WEI ET AL., *Ecological Civilization*.

[41] X. ZHOU, *Ecological Civilization in China: Challenges and Strategies*, «Capitalism Nature Socialism», 32, 3/2021, pp. 84-99.

[42] A. ZHU ET AL., *Ecological Civilization in the Making: the 'Construction' of China's Climate-forestry Nexus*, «Environmental Sociology», 9, 1/2023, pp. 6-19.

to improve the environment»[43]. The very same traits that enabled the rapid expansion of poplar plantations brought their own integral accidents, including groundwater consumption, worsening soil erosion and the spread of insect pests. As a result, according to a report published by Beijing Forestry University, only 15 percent of the trees planted since the inception of the Three-North project were still alive as of 2021[44].

This has led to a partial rethinking of the forms of governmental intervention necessary to foster the transition towards an ecological civilisation. As noted by Guofang Sheng, recently official documents abandoned an exclusive emphasis on «ecosystem construction» in favour of a more flexible terminology that combines «ecological conservation, remediation and construction, to reflect the reality of the diversity and breadth of ecological control activities in China»[45]. The attention towards ecological remediation – within and outside China – has coincided with a new way of thinking of poplars as «green infrastructures for phytoremediation and the rehabilitation of landscapes». In the last decade, the IPC has worked to convert poplar plantations into *phytoremediation infrastructures*: «using plants to clean up – or 'remediate' – contaminated soil, sediments, groundwater, surface water and air by removing, degrading and containing toxic chemicals»[46].

According to the most recent IPC report, over three million hectares of poplars across thirty countries have been planted as living infrastructures designed for such purposes. Specific poplar varieties have been selected, developed, and deployed to restore a variety of global sites: from strip-mined land in the coal and oil sands regions of Canada to military training ranges in the United States, urban sites contaminated by wastewater spills in Estonia and toxic landfills filled with cadmium in Italy[47]. In China, poplars have been reconstructed as ecological tools to manage soil pollution in industrial lands, mining wastelands and landfills. Each of these ecological engineering projects mobilises different metabolic processes characteristic of poplar trees to 'restore' ecosystems altered by urbanisation, industrial activity and military practices. Every year, thousands of poplars are planted around the world to perform as «reliable ecosystem engineers». Based on their metabolic capacity to conduct various operations of «phytoextraction», «phytovolatization», «rhizosphere

[43] H. JIANG, *Desertification in China: Problems with Policies and Perceptions*, in J. CASSIOLA, *China's Environmental Crisis: Domestic and Global Political Impacts and Responses*, New York, Palgrave, 2010, pp. 13-40. Also, H. JIANG, *Taking down the "Great Green Wall": The Science and Policy Discourse of Desertification and its Control in China*, in R. BEHNKE – M. MORTIMORE (ed), *The End of Desertification? Disputing Environmental Change in the Drylands*, Berlin, Springer, 2015, pp. 513-536.
[44] Z. KONG ET AL., *Situating China in the Global Effort to Combat Desertification*, «Land», 10, 7/2021, p. 702.
[45] G. SHEN, *Ecological Conservation, Remediation and Construction for Building an Ecological Civilization in China*, pp. 378-379.
[46] INTERNATIONAL POPLAR COMMISSION, *Poplars and Willows,* pp. 274-318.
[47] INTERNATIONAL POPLAR COMMISSION, *Poplars and Willows,* pp. 258-321. See also: J. WILLIAMS, *Phytoremediation in Wetland Ecosystems*, «Critical Reviews in Plant Sciences», 21, 6/2002, pp. 607-635.

degradation», «phytodegradation», «phytostabilization» and «hydraulic control», poplars are progressively re-imagined as «nitrogen sponges», «biopumps», «hyper-accumulators», «solar-powered pump-and-treat systems»[48].

To make poplars live – as a Great Green Wall or as a phytoremediation infrastructure – public and private projects must constantly mobilise different forms of biopolitical labour at multiple scales, from the molecular to the planetary. Agronomists and botanists develop specialised poplar varieties; plant nurseries select individual «mother trees» from which to extract and develop whole colonies of clones; regulatory agencies design the legal framework that govern planting initiatives; workers conduct planting operations on a massive scale, they engineer supporting environmental conditions, manipulate the chemical composition of the soil and attend to the trees' growth. As a result, the infrastructural poplar is recast as a bio-technical infrastructure with multiple functions: greening the desert, cleaning up toxic spills and repairing planetary metabolic cycles.

This biopolitical labour is embedded in – and interacts with – the existing infrastructural environment in complex and contradictory ways. On the one hand, plantation forestry projects rely on a complex network of technical, scientific and logistical infrastructures. Gene banks, plant nurseries, road networks, irrigation systems, national regulatory bodies and international institutions such as the IPC are all necessary nodes in a global biopolitical economy that sustains the construction and maintenance of poplar plantations. Bodily labour, social norms, power hierarchies, geopolitical projections and sovereign ambitions are reified in poplar plantations' political ecologies and bio-geometries. On the other hand, the planting of poplar trees is considered to be essential for the protection and maintenance of the territories on which more traditional infrastructural networks rest. As noted by Agnieszka Joniak-Lüthi in her ethnography of fragile connectivity in Sino-Inner Asian borderlands: «restored poplars [...] are expected to provide an ecosystem service of protecting the state-built infrastructure»[49]. Poplar plantations, in other words, constitute a living infrastructure that literally prepares and preserves the ground on which other infrastructures – such as the streets and railroad projected by the Silk Road Economic Belt – can operate, protecting them from the corrosive action of an increasingly unpredictable and extreme weather.

Ultimately, the global proliferation of poplar infrastructures exemplifies that living organisms – and the metabolic processes characterising them – are increasingly mobilised in governmental projects with diverse and even conflicting objectives. Biopower and infrastructural power converge in shaping living infrastructures

[48] This expansive web of technical concepts is deployed in official publications by the International Poplar Commission, promoting an infrastructural imagination in which the poplar appears as a flexible, living biotechnology that may be integrated in various eco-technical apparatuses. See: INTERNATIONAL POPLAR COMMISSION, *Poplars and Willows,* pp. 258-321.

[49] A. JONIAK-LÜTHI, *A Road, a Disappearing River and Fragile Connectivity in Sino-Inner Asian Borderlands*, «Political Geography», 78, 1/2020, 102122.

designed to secure highly volatile processes of socio-ecological reproduction in the Anthropocene. However, significant political differences mould the specific ways in which living infrastructures are conceived, imagined and materially built in different geographical and political contexts. In many FAO and IPC cooperation programmes, poplars have been socially constructed as *developmental infrastructures* aimed at promoting industrial forestry and rural development around the world. In China, the planting of fast-growing poplar trees – as barriers against desertification and as phytoremediation infrastructures – has been promoted not only as a way of counter-acting multiple metabolic rifts and shifts and literally prepare the ground for large-scale infrastructural and logistical projects, but also as a way of constructing alternative, eco-centric futures under the recently fashioned banner of an ecological civilisation to come. By mobilising forms of biopolitical labour that work *with* and *through* the multiple metabolic processes characterising poplar trees – from photosynthesis to phytovolatisation and phytoextraction – sovereign states and international organisations pursue multiple governmental schemes with varying forms and contents, whose relationship with global processes of capital accumulation must be further explored.

3. Carbon Plantations as Bio-Fin-Tech Infrastructures

Sovereign states and international organisations play important roles in the construction of critical living infrastructures, which mobilise the metabolic systems of poplar trees and many other life-forms. Our analysis so far has strived to show that this infrastructuralisation of living organisms has become a calculated governmental strategy: a constituent part of an emerging biopolitical economy that reconfigures and legitimises state power in the Anthropocene. Increasingly, however, global corporations are also emerging as key actors in financialised eco-infrastructural projects, which are framed as market-based solutions to the climate crisis. In this section, we interrogate the entanglements of living infrastructures with financial infrastructures. We ask how financial trading – and particularly the exchange of credits generated by 'living carbon sinks' – reconfigure socio-ecological relations of power in the so-called Anthropocene.

Carbon markets shape global political economies, geographies and ecologies. They also establish new conduits for conducting consumers' conduct and direct it towards the construction of living infrastructures. A paradigmatic global site in which this abstract process materialises and territorialises itself is located in Northern China, where the Ant Forest grows and takes root. Launched in 2016 by Alipay, currently the largest fintech platform in the world with over one billion users, Ant Forest is – first and foremost – a software application, which has been presented in

the last UN Global Climate Action Awards as «a measurable, tradable and allocable platform to shift people's daily behaviour towards a low-carbon lifestyle»[50]. Whenever users engage in so-called «green behaviours» – such as walking, hiring shared bicycles, or making paperless payments – they are rewarded with virtual «green energy points». In this way, the platform encourages consumers to purchase «green» products and services through Alipay. In exchange, users can spend their virtual energy credits by directing the planting of trees in a number of locations bordering the Gobi Desert, participating in the collective construction of an Ant Forest homonymous to Alipay's app and mirroring the virtual forest represented in its software space[51]. In this way, the digital platform constitutes a subtle *green governmentality* – a form of power aimed at steering individual behaviour towards 'smarter', 'more sustainable' choices[52].

Ant Forest is a complex eco-technical object in which digital and living infrastructures collapse into one another. It is at once a digital platform supported by server farms and data cables – enabling over 500 million users to participate in tree planting by consuming online – *and* a material and rapidly expanding ecosystem: currently consisting of over 100 million planted trees, covering a total area of 112 thousand hectares in Northwest China[53]. Based on their energy points, users can virtually plant one of several kinds of drought-resistant plants, including: apricot trees, sea-buckthorns, Chinese arborvitae, Chinese pines, rose willows, saxauls, and desert poplars. «How to plant a desert poplar?» asks a recent article in the People's Daily, the official newspaper of the Central Committee of the Chinese Communist Party. «The answer», it continues, is to «follow this plan for 321 days. 7.00 am: Get up to collect friends' green energy = 500 g of virtual green energy. 7.30 am: Take the subway to work = 52g of virtual green energy. 12.00 pm: Take-away lunch with reusable utensils = 16g of virtual green energy. 5.30 pm: Walk home (2.2 km) = 103g of virtual green energy»[54]. Performing these activities accumulates enough points to activate a little green button in the Alipay mobile app, which takes users to a screen where a poplar seedling suddenly springs up at the edges of a virtual desert.

The Ant Forest appears to emerge spontaneously from the virtual activities of online market actors, collapsing the domains of work, leisure and environmental activism into a single financialised nexus. This gamification and financialisation of

[50] UNFCC, *Alipay Ant Forest: Using Digital Technologies to Scale up Climate Action*, «UNFCC», https://unfccc.int/climate-action/momentum-for-change/planetary-health/alipay-ant-forest, accessed 15 November 2023.
[51] S. WANG – M. IBRAHIEM – M. LI, *Motivations Influencing Alipay Users to Participate in the Ant Forest Campaign*, «International Journal of Environmental Research and Public Health», 19, 24/2022, 17034. See also: G. DAL MASO, *The Promethean Ant Forest*, «Made in China», 7, 2/2022, pp. 137-149.
[52] S. RUTHERFORD, *Green Governmentality: Insights and Opportunities in the Study of Nature's Rule*, «Progress in Human Geography», 31, 3/2007, pp. 291-307.
[53] UNFCC, *Alipay Ant Forest.*
[54] M. WANYI, *China's Tree Planting Mini-program Encourages People to Green Real Desert*, «People's Daily», 9 May 2019, en.people.cn/n3/2019/0509/c90000-9576533.html, accessed 15 November 2023.

environmental action, however, risks obscuring the material and embodied labour that is expended to socially construct the Ant Forest. The complex biopolitical labour involved in planting and maintaining this living infrastructure against desertification and climate change is abstracted and made immaterial. Nowhere in the screen appears the full-time labour of the over 400,000 workers employed in China's poorest provinces, who constantly plant, water and patrol the Ant Forest. «Local farmers and herdsmen», explain an online video sponsored by Alipay, «gave up tending their flock of sheep and turned to planting and maintaining trees»[55]. In this quintessential fintech fetishism, the social relationship between urban consumers accumulating green points, rural workers planting trees, and shareholders accumulating capital is eclipsed. Instead, Alipay presents a phantasmagorical vision in which trees grow spontaneously from the everyday activities of digital consumers. An instrumental imagination of plants as infrastructural service providers is reified into uniform rows of poplar trees, while social relations are «thingified» into material structures which appear to take on a life of their own[56].

The Ant Forest is conceived to be at once a 'living carbon sink' and a 'living financial asset'. In 2021, the Chinese government introduced a new emission trading system (ETS) to encourage private investments in green infrastructures[57]. Programs of carbon capture and storage have been recognised as a way of acquiring carbon credits to be exchanged on financial markets. Tree planting has been thus turned into a financialised accumulation strategy[58]. As noted by a recent business report, since the 183,475 tons of carbon dioxide estimated to be captured by the Ant Forest might «be traded to a minimum of 3,669,500 yuan», «selling carbon dioxide emissions reductions to enterprises is an important income that Ant Forest can achieve in the future»[59]. In an increasingly financialised neoliberal environment, desert poplars on the edges of the Gobi Desert not only break sandstorms and absorb carbon dioxide; they also produce carbon credits and financial assets. They contribute to form a bio-fin-tech infrastructure, which collapses capital accumulation and climate remediation in a single arboreal fold.

Alipay's private forest is far from an isolated phenomenon. The integration of biopolitical labour into increasingly financialised networks of capital accumulation

[55] ALIPAY, *From Herdsman to Alipay Ant Forest Ranger*, «Medium», https://medium.com/alipay-and-the-world, accessed 15 November 2023.
[56] A. LOFTUS, *Reification and the Dictatorship of the Water Meter*, «Antipode», 38, 5/2006, pp. 1023-1045.
[57] A. LO ET AL., *The Neoliberal Policy Experimentation on Carbon Emission Trading in China*, «Environment and Planning C: Politics and Space», 38, 1/2020, pp. 153-173.
[58] See: G. BRYANT, *Nature as Accumulation Strategy? Finance, Nature, and Value in Carbon Markets*, «Annals of the American Association of Geographers», 108, 3/2018, pp. 605-619; S. BÖHM – M. MISOCZKY – S. MOOG, *Greening Capitalism? A Marxist Critique of Carbon Markets*, «Organization Studies», 33, 11/2012, pp. 1617-1638.
[59] J. XIONG – Q. MENG, *The Analysis of Ant Forest Business Model*, «Open Access Library Journal», 5, 1/2018, e4887. See also: N. WANG ET AL. *Quantifying the Effects of the 'Internet plus Ecology' Framework on Carbon Sink in the Digital Age: a Representative Study of Ant Forest in China*, «Environmental Research Letters», 17, 12/2022, 124005.

is a global tendency, intrinsic to the ongoing transition towards a «green» biopolitical economy increasingly reliant upon a multiplicity of living infrastructures. According to a recent study, over 60 percent of the total carbon offset credits sold on global financial markets rely on forestry projects focusing either on conservation or on tree planting. Between 2020 and 2022, the top 50 companies acquired 3.09 million carbon credits produced by tree planting projects around the world[60]. Google, for instance, has declared itself carbon neutral by investing in a variety of «high-quality carbon offsets», including forestry projects whose goal is «either to protect forests from destruction and degradation or to enhance and develop new ones»[61]. But what does it mean today to enhance and develop «new forests»? What type of infrastructural projects are sponsored by financial investments in carbon credits? And how is this financial logic reshaping worldwide forest ecologies?

In February 2023, Living Carbon – a biotech start-up based in San Francisco, which focuses on «combining advanced biotechnology with the inherent power of plants to sequester and store carbon» – made headlines by planting its first genetically engineered, «photosynthesis-enhanced» poplar plantation[62]. This bio-technical development builds upon decades of research and experimentation: since the 1970s, the poplar has been adopted as a model tree in forest genetics due to its fast growth and ease of reproduction by cloning. In 2006, the first tree to have its genome completely sequenced and published was *Populus trichocarpa*, a variety of poplar chosen for its economic and scientific importance as an experimental organism. Sequencing the poplar genome took over four years of collaborative labour by hundreds of scientists working through an international joint venture involving 38 institutions across the EU, North America and China, and coordinated by the U.S. Department of Energy's Joint Genome Institute[63]. The publication of a poplar genomic sequence led to a further boom in genetic experimentation with poplar trees, mostly aimed at developing new transgenic varieties whose engineered metabolism would better serve the necessities of mechanised industrial forestry. Research efforts on GM poplars – currently conducted in at least 21 countries – have mostly focused on traits that serve industrial plantation ecologies: herbicide tolerance, pest resistance, drought and salinity tolerance and improved growth rate. By the early 2000s, several varieties of genetically modified poplar have been developed,

[60] J. GABBATISS, *How Some of the World's Largest Companies Rely on Carbon Offsets to 'Reach Net-zero'*, «Carbon Brief», https://interactive.carbonbrief.org/, accessed 15 November 2023.
[61] GOOGLE, *White Paper: Google's Carbon Offsets*, «Google», https://www.google.com/green/pdfs/google-carbon-offsets.pdf, accessed 15 November 2023.
[62] G. POPKIN, *For the First Time, Genetically Modified Trees Have Been Planted in a U.S. Forest*, «The New York Times», 16 February 2023, https://www.nytimes.com/2023/02/16/science/genetically-modified-trees-living-carbon.html, accessed 15 December 2023.
[63] G. TUSKAN ET AL., *The Genome of Black Cottonwood, Populus trichocarpa (Torr. & Gray)*, «Science», 313, 5793/2006, pp. 1596-1604.

patented and commercialised, leading to the establishment of experimental GM poplar fields in several countries[64].

The targeted genetic mutation introduced by Living Carbon aims to accelerate the metabolic process by which trees convert carbon dioxide into sugars and, ultimately, wood by «improving the poplar's relatively inefficient C3 photosynthetic pathways». In this case, the metabolic pathways characterising the poplar as a biological, living organism are purposefully redesigned to increase its carbon capturing capacities and turn it into a more efficient living means of carbon-credit-production. According to a peer-reviewed publication by Living Carbon's scientists, the resulting climate-smart seedlings show «53% more above-ground biomass than controls after five months» and a considerable increase in «plant height, stem volume growth, carbon assimilation rate, and biomass accumulation»[65]. «By increasing the efficiency of photosynthesis», writes Living Carbon in its promotional material, «we can help trees grow faster and act as partners in capturing more carbon from the atmosphere». The company, which publicises itself as «a public benefit corporation where we can create value for our shareholders and also take actions that align with our mission», presents its corporate mission as a bio-geo-engineering project, operating at multiple scales from the molecular to the planetary[66]. Its corporate laboratories redesign metabolic processes of biochemical conversion – continuously taking place at the molecular scale within each «photosynthetically-enhanced» poplar tree – in order to shape planetary biogeochemical cycles, model the biochemistry of the atmosphere, and fix the global climate. They engineer GM poplar plantations designed to perform as bio-technical infrastructures for carbon capture and storage, but also as living means of production specialised in the generation of carbon credits.

The start-up has received a $500,000 grant from the US Department of Energy and raised over $36 million in the first round of funding led by Singapore's sovereign wealth fund Temasek and Toyota Ventures. The CEO of Toyota Ventures explained the reasoning behind the investment as part of an attempt to capture a voluntary carbon credit market predicted to exceed $50 billion by 2030, while presenting «Living Carbon's synthetic biology platform» as a way of mobilising

[64] Field trials dedicated to experimentation with GM poplars have been reported in at least nine countries, including the US, France and Germany. In China, two varieties of transgenic Bt poplars have been approved for commercialisation by the State Forestry Administration, leading to a rapid expansion of experimental GM poplar plantations that currently cover an area of over 450 square hectares. G. WANG ET AL., *The Current Status and Development of Insect-resistant Genetically Engineered Poplar in China*, «Frontiers in Plant Science», 9, 1/2018, pp. 1408-1422; and A. THAKUR ET AL., *Achievements and Prospects of Genetic Engineering in Poplar*, «New Forests», 52, 1/2021, pp. 889-920.
[65] Y. TAO ET AL., *Enhanced Photosynthetic Efficiency for Increased Carbon Assimilation and Woody Biomass Production in Engineered Hybrid Poplar*, «Forests», 14, 4/2023, pp. 827-828.
[66] EDITORS, *Hacking Trees*, «Grow Magazine», 1, 2/2023, pp. 15-18.

«genetic engineering to deliver high-quality carbon credits to the market»[67]. Directing the business strategies of biotech companies such as Living Carbon, finance becomes a biopower that continuously reshapes botanical physiologies and forest metabolisms. Once trees are invested by the financial logic of carbon credit markets, the calculations of investors become a material force capable of steering the course of natural history. In this case, for instance, financial incentives promote the genetic manipulation of the C3 photosynthetic pathway, and the splicing of «genes from pumpkin and green algae into poplar trees», as biotechnical operations worthy of capital investments and industrial scaling up[68]. The financialisation of life, in other words, entails two complementary aspects: life-forms are increasingly transformed into financial assets; and finance into a life shaping force.

Even if the newly planted GM poplars are only beginning to remove carbon from the atmosphere, the company is already selling carbon credits to corporate clients on financial platforms such as CO2.com, Patch and Watershed. This financial model – based on «securing forward commitments for tons that will be removed in the future» – poses a number of questions concerning the temporality of carbon removal projects. Companies offset ongoing carbon emissions based on the promissory value of the poplar tree, whose metabolism is imagined tocontinue performing as expected in an increasingly uncertain future. Yet, poplars do not always perform as expected. As we have seen, poplar infrastructures often fail spectacularly due to pest invasions, plant epidemics and forest fires. While constructed as promising techno-ecological fixes to climate change, carbon plantations generate their own integral accidents in the form of unexpected ecological effects and consequences[69]. Molecular biologists, for instance, have recently expressed concern over the expansion of poplar plantations since, «on a warming planet, plants like oaks and poplars will emit more of a compound that exacerbates poor air quality, contributing to problematic particulate matter and low-atmosphere ozone»[70]. This unexpected finding is indicative of the extent to which living infrastructures - including Living Carbon's GM poplar plantations - remain contested and contradictory terrains: «troubled ecologies» that seldom function «as perfections of capital's capacity

[67] J. FIALKA, *Start-up Hopes 'Super' Poplar Trees Will Suck Up More CO2*, «Scientific American», 9 February 2023, https://www.scientificamerican.com/article/start-up-hopes-super-poplar-trees-will-suck-up-more-co2/.

[68] EDITORS, *GM Forests for Carbon Removal Planted in US*, «Nature Biotechnology», 41, 1/2023, p. 306.

[69] «Every technology carries its own negativity, which is invented at the same time as technological progress. [...] When you invent the ship, you also invent the shipwreck; when you invent the plane you also invent the plane crash; when you invent electricity, you invent electrocution etc.» We extend Paul Virilio's theory of the integral accident to biotechnologies and living infrastructures (P. VIRILIO, *Politics of the Very Worst*, New York, Semiotext(e), 1999, p. 89).

[70] A. SAHU ET AL., *Hydroxymethylbutenyl Diphosphate Accumulation Reveals MEP Pathway Regulation for High CO2-induced Suppression of Isoprene Emission*, «Proceedings of the National Academy of Sciences», 120, 41/2023, e2309536120. The question is posed in the context of a related interview: EDITORS, *Plants Could Worsen Air Pollution on a Warming Planet*, «Science Daily», 2023, https://www.sciencedaily.com/releases/2023/10/231005161736.htm, accessed 15 November 2023.

to exploit nature», but rather represent «experimental (and remarkably unstable) projects on and with other beings»[71].

More generally, ecologists have pointed out that the «current trend of carbon-focused tree planting is taking us along the path of large-scale biotic and functional homogenisation for little carbon gain»[72]. A recent study published in *Science* has estimated that only 6 percent of voluntary carbon credits sold on global markets in 2021 were actually associated with cuts in carbon emissions[73]. This exposes a number of intrinsic issues with carbon trading schemes promoting carbon capture and storage projects such as Living Carbon's GM poplar forests. First of all, these schemes have historically performed poorly against the objective of reducing carbon emissions. This is itself linked to the contradiction inherent to using financial trading as an allocative planning mechanism for the planet's forests. Financial trading of carbon credits furthers the dictatorship of the abstract over the concrete, obscuring the complex multispecies ecologies of labour enrolled in the planting and maintenance of these infrastructural forest plantations.

Moreover, and more fundamentally, a growing body of literature has strived to show how carbon trading re-entrench colonial patterns of uneven exchange and value extraction.[74] New forms of calculative reason enrol forests all over the world into global financial markets and their (neo-)colonial rationalities[75]. Recently, Bolivian president Luis Acre warned that carbon trading under the United Nations Framework Convention on Climate Change – including REDD and REDD+ initiatives – constitutes a «new carbon colonialism», which transforms fertile lands in the Global South into carbon sinks designed to balance the atmospheric pollution generated by industrial activities mostly serving the Global North[76]. In view of this analysis, the recent boom in carbon plantations – i.e. single-species, commercial plantations designed to capture excess carbon from the atmosphere – reveals a certain continuity between the present global economy and the logic inherent to colonial exploitation: global ecosystems are being re-organised in order to support the accumulation of wealth and capital in the Global North. As Keston Perry has argued, «finance operates as an entanglement of power relations accruing rent from

[71] See: S. BESKY – A. BLANCHETTE (eds) *How Nature Works: Rethinking Labor on a Troubled Planet*, Albuquerque, University of New Mexico Press, 2019, pp. 6-7.
[72] J. AGUIRRE-GUTIERREZ ET AL., *Valuing the Functionality of Tropical Ecosystems Beyond Carbon*, «Trends in Ecology & Evolution», 38, 12/2023, pp. 1109-1111.
[73] T. WEST ET AL., *Action Needed to Make Carbon Offsets from Tropical Forest Conservation Work for Climate Change Mitigation*, «Science», 381, 6660/2023, pp. 873-877.
[74] K. PERRY – L. SEALEY-HUGGINS, *Racial Capitalism and Climate Justice*, pp. xx
[75] See: N. DIENG – A. KARSENTY, *Power through Trees. State Territorialisation by Means of Privatization and 'Agrobizforestry' in Côte d'Ivoire*, «World Development Sustainability», 4, 1/2023, 100074; R. MYERS ET AL., *Messiness of Forest Governance: How Technical Approaches Suppress Politics in REDD+ and Conservation Projects*, «Global Environmental Change», 50, 1/2018, pp. 314-324.
[76] F. SULTANA, *The Unbearable Heaviness of Climate Coloniality*, «Political Geography», 99, 1/2022, 102638. For more details on REDD and REDD+ initiatives, see: J. CABELLO – T. GILBERTSON, *A Colonial Mechanism to Enclose Lands: A Critical Review of two REDD+-focused Special Issues*, «Ephemera», 12, 1/2012, pp. 162-180.

climate devastation», by which the entanglements of finance and forests «constitute an ongoing and evolving relationship between the colonial/postcolonial world that restructure relations in the present context»[77]. Rent extraction through green finance constitutes an increasingly important means of redistributing wealth from the public to the private sphere, as well as from the Global South to imperial countries. Climate policy is financialised and rent-capture greenwashed, reconfiguring centuries-long colonial patterns of extraction and control.

Carbon plantations as 'living infrastructures' are presented as a 'fix' for the socio-ecological crises represented by the so-called Anthropocene; yet they exist in a problematic tension with the violent historical geographies of plantations as drivers of socioecological transformation. In a recent article, Janae Davis and co-authors suggest that the emergence of an industrial plantation economy was both the threshold and the driver of the new geological epoch. As they point out, the concept of the «Plantationocene» represents a critical alternative to hegemonic conceptualisations of the Anthropocene epoch, which centres how plantation economies fundamentally reshaped the biogeochemistry of the Earth[78]. In Aikens and colleagues' words, the Plantationocene «place[s] plantation not only at the heart of Western modernity, but also conceive of it as a central engine of capitalism, empire, industrialisation, ecological destruction, geological change, and climate change». As they point out, the «kinds of ecological simplification, biological movement, and technological development» necessary for the construction of plantation ecologies would not have been possible without «Indigenous removals, captive and exploited labour, forced human relocations, and human rights violations»[79].

We may ask, following Katherine McKittrick: «What is at stake in linking a plantation past to the present? What comes of positioning the plantation as a threshold to thinking through long-standing and contemporary practices of racial violence?»[80]. If the plantation with its racist and uneven ecologies of life and death are at the root of modernity and of the so-called Anthropocene, where does that leave the monocultural poplar plantation as an antidote to the ecological crises of that epoch? To what extent do carbon plantations such as Living Carbon's GM forests reconfigure and financialise colonial fantasies of biological mastery and control? To what extent do they constitute a further extension of global tendencies towards the financialisation of life and the reshaping of global ecosystems in the service of carbon-emitting corporations?

[77] K. PERRY, *The New 'Bond-age', Climate Crisis and the Case for Climate Reparations: Unpicking Old/new Colonialities of Finance for Development within the SDGs*, «Geoforum», 126, 1/2021, pp. 361-371.
[78] J. DAVIS ET AL., *Anthropocene, Capitalocene,... Plantationocene?: A Manifesto for Ecological Justice in an Age of Global Crises*, «Geography Compass», 13, 5/2019, e12438; See also: M. JEGATHESAN, *Black Feminist Plots before the Plantationocene and Anthropology's "Regional Closets"*, «Feminist Anthropology», 2, 1/2021, pp. 78-93.
[79] N. AIKENS ET AL., *South to the Plantationocene*, «ASAP Journal», 17, 1/2019: e7591.
[80] K. MCKITTRICK, *Plantation Futures*, «Small Axe: A Caribbean journal of criticism», 17, 42/2013, pp. 1-15.

All these questions remain contested. Significant differences must be recognised between the multitude of bio-infrastructural projects currently pursued by public and private actors in different geographical, political and ecological contexts across the planet. However, the recent reinvention of monoculture forestry plantations as promissory biotechnological fixes to the climate crisis risks reinforcing (neo-)colonial dynamics in the highly financialised global present. This for two essential reasons: they do nothing to repair the violence caused by plantation pasts; and second, they further a financialisation of biological life that increasingly convert global ecosystems in many parts of the world into functional carbon sinks, mostly servicing major carbon-emitting corporations. As Laura Pulido has effectively argued, climate change not only has deeply racialised effects, but racist roots[81]. This fundamental recognition begs the question of whether any attempt to address climate change without explicit steps towards reparations to people historically dispossessed in the ongoing plantation-capital-colonial epoch risks further entrenching the very dynamics which spurred the acceleration of industrial impact on the biosphere.

4. Conclusion

The recent recognition that the Earth has entered a new geological era, characterised by an ongoing Great Acceleration in industrial production and pollution, infuses urgency to proliferating attempts to engineer living infrastructures designed to secure processes of social reproduction threatened by climate change, desertification, rising sea levels, etc. The existential threat represented by multiple ongoing shifts in the biogeochemistry of the planet is increasingly recognised, fuelling a desperate search for new forms of infrastructure designed to contain the rapidly proliferating socio-ecological crises that ravage the biosphere.

In the context of current debates concerning the Anthropocene, we interrogated ongoing processes of infrastructuralisation of living organisms such as oysters, goats and trees. These forms of life are increasingly being mobilised as living infrastructures to protect coastlines, metabolise waste and control wildfire. They have been turned into functional elements of state biopower, promoting new conceptions of historical time and of political legitimacy. While all infrastructures are essentially biopolitical insofar as they shape both biological and social life, living infrastructures set in play a multi-species biopolitical economy that increasingly relies on the development of a technoscientific knowledge of biological processes and new means of manipulating them.

[81] L. PULIDO, *Racism and the Anthropocene*, «Future Remains», 17, 1/2018, pp. 116-128.

Poplars have served as an important socio-ecological nexus in this ongoing transformation. States, international organisations, botanists and silviculturists participate in the social construction of poplar plantations as living infrastructures designed to provide multiple ecosystem services. The biopolitical labour of selecting seedlings, multiplying clones and planting trees according to carefully designed biopolitical geometries is directed towards the construction of green barriers against advancing deserts, bio-pumps metabolising toxic waste and carbon sinks removing carbon from the atmosphere. Yet, the construction of poplar infrastructures remains a contested and inherently unstable operation, profoundly tied in with functionalist views of ecosystems. Poplar infrastructures do not always perform as expected, creating new sorts of uncertainties and risks.

Gene editing and carbon credits are transforming finance into a life-shaping force, which guides the construction of poplar plantations into complex bio-technical infrastructures for climate mitigation and capital accumulation. Financialised projects of carbon capture and storage – such as Alipay's Ant Forest and Living Carbon's photosynthesis-enhanced plantations – are a constituent part of an emergent biopolitical economy, which is increasingly reliant upon the construction of a multiplicity of living infrastructures, the extraction of labour from exploited human bodies, and the displacement of other forms-of-life from global ecosystems. Carbon plantations are conceived as living infrastructures for the Anthropocene, whose construction seeks to fix and repair the biogeochemical rifts and shifts caused by the modern Great Acceleration. Yet, paradoxically, they often rely on modernist aspirations of biological mastery and ecological control, while showing the potential to re-entrench colonial patterns of uneven exchange and value extraction.