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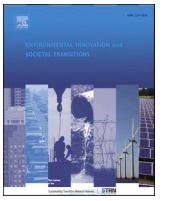

Decolonising innovation in sustainability transitions for pluriversal justice and wellbeing

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ABSTRACT

Sustainability scholars address social-ecological injustices associated with innovation processes, through concepts such as 'just transitions' and 'energy justice'. However, the making of today's innovations by *deep and pervasive formations of power and privilege – colonial modernities* – is currently neglected in sustainability transition studies. We conceptualise nine epistemological and ontological foundations of distinctively colonial-modern innovation processes. These foundations include: fixing categorical divides on flowing relations; stratifying rigidly separated orders; promoting appropriation of privileges; objectifying and reifying realities; monopolising quantifications; standardising practices; singularising ontology, by approaching the pluriverse (of many different and connected ways of knowing, being and doing in disparate worlds) as just one world; and dominating other worlds by colonial-modern worldmaking.

Taken together, these interwoven foundations point to the following actions to help decolonise modern innovation processes: recognising and *challenging colonial formations* of concentrated power and privilege as they are built into modern knowing; *extending egalitarian relations* towards intersectionally marginalised contributors in knowledge production; *grasping multifarious encompassment* by wider material and living ecologies of beings notionally separated as 'human' or 'nonhuman'; *embracing inherent uncertainties* in all that can be known or made, to imbue knowing and making with humility and care; *admitting open pluralities* of qualities, which include approaching dimensions of categories as fluid; and *supporting pluriversal reparations* spanning many ways of knowing, in struggles to dismantle coloniality everywhere. Decolonising innovation processes in these ways, we propose, can contribute to deeper decolonial transformations of modernities in solidarity with colonially subordinated peoples' *struggles for pluriversal wellbeing and justice*. Without realising such justice for the flourishing of many worlds, sustainability may remain little more than a modern illusion.

1. Introduction

It is widely recognised that innovations in sustainability transitions are structured by different kinds of social-political power

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(Lawhon and Murphy, 2012; Avelino, 2021). Scholars examine how power impedes transformative innovation by entrenching material, cognitive and normative structuration (e.g., in sociotechnical regimes) (Avelino and Wittmayer 2016; Kok 2023). They also study how radical innovations for sustainability may be designed, used and managed while exacerbating asymmetric relations of power (Avelino et al. 2023; Feola et al. 2021). However, the conditioning of innovations by globally hegemonic formations of power and privilege – conceptualised as *colonial modernity* (Mahadevan 2002; Mignolo 2011) – is currently neglected in transitions studies (Arora and Stirling 2023). This neglect persists despite recognitions of the need and urgency of 'decolonisation' in transitions (Ghosh et al. 2021). By harnessing colonially concentrated power and privilege in the present, the particular patterns of innovation associated with colonial modernities inflict multiple social-ecological injustices that are addressed by sustainability scholars through concepts like 'just transitions' and 'energy justice' (Forget and Bos, 2022; Stark et al., 2023; Avelino et al. 2024).

Beyond Global North-South inequalities in the distribution of benefits and costs of sustainability transitions (Jenkins et al., 2018; Brown et al., 2024), colonial modernities' constituting injustices include violent dispossessions of lands and resources from racialised and Indigenous communities for renewable energy developments (Avila-Calero, 2017;Normann, 2021); appropriation of ideas and concepts from colonised peoples (eg: Altmann, 2020); the marginalisation of those voices that are marked as structurally 'backward' in ostensibly participatory consultation processes around new technologies (Ilizarbe, 2019; Ghosh and Arora 2022); and wider attempts to cultivate selective amnesia towards histories of colonial genocides and transcontinental enslavement (Stoler, 2011; Schneider, 2024), in order to evade imperial metropoles' responsibility of enacting reparations (Táíwò, 2022).

In struggles against such injustices, we argue, it is crucial to *confront and transform innovation processes* that are central to colonial-modern worldmaking. With mainstream policy understandings seeing innovation as "the successful development and application of *new knowledge*" (OECD 2008: 17, emphasis added), we focus on conceptualising modern knowledge production's epistemological and ontological foundations. These conceptual foundations highlight that innovation is not just techno-scienfic but also simultaneously social, political, ecological and cultural (Ghosh et al., 2025). We illustrate these foundations using brief examples from genetic engineering in agriculture and from technocratic smart urbanisms, which span conventional categorisations between radical and incremental innovations, sustaining and disruptive innovations, and product and process innovations (OECD 2023).

We propose nine interrelated epistemological and ontological foundations of colonial-modern knowledge production. In focusing on knowledge, these foundations build on the more general social-material dimensions of colonial modernity conceptualised by Arora and Stirling (2023). The nine foundations are sketched here not as settled, definitive or complete, but as a more contingent and open-ended weaving of concepts for ongoing processes of analysis and wider political struggles to decolonise innovation:

A) **hardening categories**: by *privileging rigid borders of defined categories* rather than more flowing relational constitution of differences;
B) **stratifying orders**: through *hierarchical structuring of rigidly asserted distinctions* in and between cultures and natures;
C) **appropriating privileges**: through technologically mediated (land) *grabs and* (resource) *extractions from 'subordinated' natures and nationalities*, races and religions, castes and colours, ethnicities and sexualities, intersecting with gendered dominations;
D) **controlling objectivity**: in approaching nonhuman (and human) beings as lacking in emotions and (cognitive) autonomy, for *attempting control over 'subordinated' entities*;
E) **reifying representations**: by concretising realities in representations (composed of numbers and words), while *suppressing uncertainties*;
F) **monopolising quantifications**: to materialise an obsession with scalar magnitudes along predefined categorical dimensions, while *marginalising an open plurality of qualities*;
G) **standardising practices**: for *attempting homogeneities* through one-size-fits-all imaginaries, laws, policies, protocols and equipment;
H) **singularising ontology**: to obscure or *assimilate diverse artisanal and/or Indigenous ways of knowing* into colonial-modern patterns of innovation;
I) **dominating worlds**: developing and deploying innovations to make modern patriarchal-nationalist and techno-capitalist worlds, while *subordinating and damaging* pluriversal realities and *marginalising* associated possibilities of convivial wellbeing.

We argue that without confronting such foundations of colonial-modern innovations and associated worldmaking, interventions for social-ecological justice and wellbeing can seem like 'turning on the faucets in a burning house'. Even where burning injustices are approached structurally, their critical significance is substantially diminished by attribution to more circumscribed political formations like global capitalism and supply chains (Feola 2020; Sovacool et al. 2021). In such circumscribed framings, epistemological and ontological foundations of colonial-modern worldmaking are generally neglected. It is through those constituting foundations that crucial innovations for 'green transitions' are developed, such as Lithium-ion batteries that entail social-ecological harms during mining, production and after use (Murdock et al., 2021); and solar geoengineering that claims to tackle climate change while embedding the hubris of complete control over a categorically separated 'nature' (Gunderson et al. 2018). In short, without confronting those epistemological and ontological foundations, re-enactments of colonial injustices through modern innovations for sustainability can go unaddressed and unchecked (Arora and Stirling 2023; Stirling 2024). Struggles for 'just transitions' and wider 'social-ecological wellbeing' thus require decolonisation of modern innovations across all areas of activity from food and conservation to energy and mobility.

Particular implications arise here for wellbeing as a core thematic focus of this special issue. We will return to these in addressing pluriversal justice in our conclusions. For now, we begin with a brief overview of some key interlinkages between literatures on wellbeing and analyses of justice in relation to sustainability transitions. This will be followed by a discussion focusing in detail on each

of the nine foundations named above. Description of each of these foundations is accompanied with a brief outline of connected **decolonial struggles**.

1.1. Grasping justice and wellbeing in transitions

Central to many perspectives on human wellbeing (Sen 1999 Schlossberg 2007; Nussbaum 2011), conceptions of justice are now widely debated in sustainability transitions (Avelino et al., 2024; Kumar et al., 2021; Williams & Doyon, 2019). Building on a longer tradition in environmental justice literatures, benefits and harms of socio-ecological-technical changes are recognised as unequally distributed among different actors and groups, across energy, mobility, food and other areas of socio-technical activity (Jenkins et al., 2018; Kaljonen et al., 2021; Williams & Doyon, 2019). In this context, arguments of *distributive justice* are employed to address inequalities through fair allocation of benefits and harms. This form of justice is central to crucially important ideas of wellbeing associated with Amartya Sen's work on human capabilities (Sen 1995; 1999).

However, such conceptions of justice and wellbeing can neglect how injustices are produced in the first place, through power-laden historical, cultural, structural and institutional processes (of innovation). These processes may be examined in terms of racial capitalism for example, which places "contemporary forms of racial inequality in a materialist, ideological and historical framework" (Pulido, 2017: 527). Attending to global and local contexts of racial capitalism, may help foreground how racially marginalised communities are rendered less deserving of justice than white communities undergoing sustainability transitions (Perry 2023). Distributive aspects of human wellbeing – relating to health, dignity, and life chances – are all systematically curtailed by structural injustices that are historically engendered (e.g., through colonialism, slavery), economically entrenched (e.g., global trade regimes, debt) and politically maintained (Farmer 2004).

Sustainability transitions studies are beginning to address injustices of misrecognition, marginalisation and exclusion associated with historically entrenched socio-political hierarchies. It is here that *procedural justice* is often foregrounded to address fairness in transition processes rather than just in distribution of their outcomes. Procedural justice directly addresses political processes of governing sustainability transitions (Avelino et al., 2024), and can be seen as focused on "representation and participation of a wide range of stakeholders" in innovative developments for energy transitions (Späth et al., 2022). It can also include transparency of information along with various techniques of facilitating, orchestrating, steering, and consulting a variety of stakeholders in order to ensure a just process (Heffron, 2021). These process-focused aspects of justice are strongly reflected in understandings emphasising "the relational dimension of wellbeing" (White 2010). However, techniques of facilitating and steering of participatory processes intended to address procedural justice and relational wellbeing, can fix agendas in alignment with dominant political formations. In this way they can inadvertently reduce participation to ceremonial exercises that convey an impression that (pre-decided) innovation patterns such as digital cities have widespread public acceptance (Ghosh and Arora 2022).

Crucial for procedural justice is the identification of all those who are excluded from governance processes. Democratic recognition of who is excluded/included may be understood as deliberative justice (Sheller, 2018). More generally, this "pro-active recognition of persons" (Petzer et al., 2020), may be seen as *recognitional justice*. However the issue of recognition goes far beyond the identification of those who are excluded from governance processes, even ostensibly participatory ones. It is rather a question of recognising (violations of) people's rights, dignities, needs, experiences, interests and identities over time and space (Van Uffelen, 2022). It is these recognitional aspects that are arguably most prominent in articulations of wellbeing in Nussbaum's (2000) contributions to the capabilities approach as well as in subsequent feminist perspectives on wellbeing (Lynch et al. 2009). Central to recognitional justice and wellbeing thus are sociopolitical contexts beyond those focused on deliberation (for governance of innovation) *per se*. Recognition clearly has a wider and deeper historical-cultural dimension (Avelino et al., 2024), which may mean taking intersecting structural oppressions of race and gender seriously. More generally, recognitional justice may require addressing colonial imprints on all kinds of (material) relations within and between modern societies in the Global South and North.

Conceptions of justice are Eurocentric if they treat particular 'Western' values or theories as 'superior' or 'universal' (Álvarez and Coolsaet, 2020). Such conceptions can neglect or obscure colonial violence and extraction in the past and present, which are central to producing 'Western' (or Northern) concentrations of power and privilege. Calls for *reparative justice* challenge such attempts to cultivate selective historical amnesia (Sriprakash et al., 2020). Reparative justice thus involves compensation, restitution and reconstruction to address past and present wrongs done to victims and survivors of colonialism, of white supremacy and of enslavement (Táíwò, 2022; Eugene et al. 2024). While this may not focus on flourishings of many worlds devastated by colonial modernities (Arora et al. 2025), it does reparatively reorient understandings and practices around wellbeing away from colonial-modern norms and metrics towards firmer groundings in affects, precarities and historical injustices (Berlant 2011).

In sustainability transitions, reparative justice is often aligned with the idea of restoration. Restorative justice – borrowed from criminal studies – points to 'healing processes' that may foreground 'indigenous worldviews' (Avelino et al. 2024). It may be invoked to address harms associated with energy transitions to net zero (Heffron and Hazrati, 2024). Restorative justice can also require corrections to imperial amnesia. Colonisers' ostensible 'inability to remember' intersectional oppression and dispossession is "not an innocent forgetting, but an integral, structural part of the colonial process." (Schneider, 2024: 3). Such considerations are central in countering new amnesias being enacted through 'carbon colonialism' and 'climate coloniality' that mask historical responsibilities of the 'West' and other concentrations of privilege to reduce emissions and finance mitigation and adaptation in the South (Kumar et al., 2021; Späth et al., 2022; Sultana, 2022)

Dominant Eurocentric conceptions of justice also mean the exclusion of other meaningful understandings of what it means to live in a just world. The latter understandings have been produced by many diverse peoples through history (e.g., Salamon and Lee, 2024). This links with the wider erasure of Indigenous and artisanal ways of knowing by colonial modernity (Arora and Stirling, 2023). It also

resonates with seminal critiques of parallel Eurocentric biases affecting so much work on human wellbeing (Li 2007). Scholars have termed the universalising obsessions with dominant modern framings as 'epistemicide' (Grosfoguel 2013), through which a multiplicity of innovative knowledges and wisdoms are marginalised (that are often grounded spiritually in socioecological relations). This marginalisation and associated hierarchies between ways of knowing are addressed by calls for *epistemic justice* (Ghosh et al. 2021; Cummings et al., 2025). Prevalent hierarchies between ways of knowing mean that epistemic injustice is inflicted, for instance, when individualising and reifying framings of impoverished people's agency (or the presumed lack of it) end up marginalising people further (Schipper and Mukherji, 2024; Sharma et al., 2021). Such marginalisation may in particular be enacted through modern governance interventions.

We conclude this section by noting that barring some notions of restorative and reparative justice, conceptions of justice and wellbeing in sustainability transitions are very rarely considered as being enacted outside the ontological confines of colonial modernity's 'one-world world' (Arora and Stirling 2023). Whilst asymmetries of power and privilege underpinning injustices may be acknowledged across societies in the North and South, colonial modernity's ontological confinement obscures more openly relational, fluidly processual and interminably plural ways of knowing. Often categorised as 'traditional', these ways of knowing are nurtured by hundreds of colonially subordinated Indigenous and artisanal ways of living that resist, survive and sometimes thrive among the Earth's 'many worlds' (de la Cadena and Blaser 2018). Considered collectively in struggles for decolonising innovation, these pluriversal ways of knowing grounded in multiple ontologies are less susceptible to the pervasively extracting, appropriating, controlling and supremacist effects of power and privilege (Arora and Stirling, 2020), to which colonial-modern innovations are so particularly vulnerable.

1.2. Epistemological and ontological foundations of modern innovation

In the following, we discuss nine interconnected epistemological and ontological foundations that constitute modern knowledge production for innovation. While some combination of these conceptual foundations can find relevance in grasping a whole range of modern innovations, we narrate brief examples from either smart city developments or agricultural genetic engineering to illustrate each foundation. For relating these illustrative examples, we rely on secondary literature. As our arguments are centred on the global formation of colonial modernity, we do not focus on a particular region, country or city.

1.2.1. Hardening categories

Starting with the division of 'nature' from 'cultures', a central constituting foundation of colonial-modern innovation processes is that their knowledges delineate, privilege and settle categorical separations. Embedding colonial ambitions to control reality for 'divide and rule' (Arora et al. 2020), modern categorisations are rigidly fixed over plurally situated and *flowing relations* spanning nature-cultures or other socially constructed categories. This process can lead to the neglect of some fundamentally important and expansively salient attributes of realities. Crucially neglected here are connections and flows that make up all 'things' – refracting them across contrasting contexts and constantly changing their forms (Inada 1974; Whitehead, 1978). By segregating and boxing up 'things' in social-cultural, natural-ecological or otherwise-divided kinds of realities, colonial modernity imprints and *hardens categorical divides* in all fields of knowledge and technology.

This foundation of colonial modern knowledge production is critical because – whatever (human and nonhuman) phenomena or contexts are in focus – it is flowing relations along with prior categories of salient entities and structures which are central in constituting constructs of understanding (Callon 1998; Latour 2005; Mol 2002; Strathern, 2005). In particular, relations are typically just as formative as any supposedly 'pure', 'objective' or 'complete' sets of attributes treated as essentially inherent to a focal natural or cultural 'thing'. After all, how else than through perceived and conceived relations, can meaningful distinctions be drawn, comparisons made, conditions set, and articulations proposed – according to which any contingently grasped thing weaves into wider fabrics of being and becoming?

A series of important implications arise in this colonial tendency to rigidly define and settle categories in modern knowledge production (Cohn 1996; Mamdani, 2012). Categories hardened in modern imaginations and enactments of reality, tend to stabilise specific selected meanings and attributes over others that are in principle equally relevant (Strathern, 2005). For instance, in ideas of nation, a particular religious, racial or ethnic identity may be selected and prioritised not only over diversities of alternative identities but also over intercultural flows and mixes. Through such selection and prioritisation processes, colonial modernity's knowledge developments are deeply susceptible to concentrations of power and privilege: dimensions of meaning that are most prominently upheld as fitting or apt, tend to be those that are typically the most expedient (Stirling 2008; 2015).

Examples of this syndrome of rigid categorisation can be recognised in genetic modification technologies in agriculture. In ways that reflect privileged disciplines and powerful interests enacting the appropriation and assertion of intellectual property rights, categorically hardened imaginations of 'the gene' are highly central in promotional policy and academic discourses (Arora et al. 2020). These imaginations gloss over complex biochemical and cytological relations and processes interacting with genomes, which disrupt the simplistic imagination that particular genotypic features correspond one-to-one with specific phenotypic traits (Falk 1991; van Speybroeck 2002).

In a broader sense, the category 'nature' (separated from cultures) itself has by this means been defined as if key formative characteristics are singular, fixed and self-evident (cf. Whitehead, 1920). Highlighted categorical features taken to constitute 'relevant' aspects of nature, are strongly reflective of narrowly selected and highly specific political-economic interests (eg: of resource extraction) across different cultural contexts (Jasanoff, 2005). So the categorical definitions of and in 'nature' that constitute genetic manipulation imaginations, are at the same time rigidly bordered (by deleting relational entanglements) and deeply reflective of the

'cultures' from which they are viewed.

That colonial modernity privileges narrow and rigid categorical borders means that **decolonial struggles** involve shifts towards *expansively relational understandings*. To strive towards this in ways that do not simply implicate our own privileging of categorical borders between 'problems' and 'solutions (and inadvertently reproduce the colonial modern syndromes that we aim to resist), such shifts involve grasping how extant modern categories are themselves relationally constituted.

Decolonial struggles thus involve deeper grasps of how prevailing modern categories, including those of nations and sciences, can hide diverse relational flows that cut across all kinds of borders. This involves recognising that focal constructs in any setting (from 'nature' and 'culture' to 'genes', 'traits' and 'nations') are openly *polythetic* rather than decidedly monothetic (Cairns et al. 2021; Arora et al. 2023). This means that no focal construct of understanding – no category – is fully definable by any settled array of necessary or sufficient attributes. Polythetic definitions by contrast, admit much more open, flexible and ambiguous arrays of plural characteristics, collectively resolving broadly resonating *affinities* rather than any supposedly rigid categorical attributes. Enacted on prior constructs (Arora and Stirling 2023) – around gender, race, class, sexuality, ability, nationality, religion, ethnicity, or tribe, species, and indeed genes – polythetic modes of apprehension can disrupt colonial-modern categories that are singularly defined and notionally settled.

By introducing more relational, processual and contextual knowledges for decolonising modern innovation processes, polythetic understandings may help open up political space for onward struggle to disobey rigidly settling definitions of modern categories (cf. Mignolo, 2009, on epistemic disobedience). We hope that such knowledges in turn can both strengthen traction for subaltern perspectives and interests in particular settings, while also prefiguring deeper and wider decolonial pluralisms (see sections 1.2.8 and 1.2.9, titled Singularising ontology and Dominating worlds).

1.2.2. Stratifying orders

It is well-established in Science, Technology and Society (STS) studies that the content of knowledge is co-produced with the social orders in which it takes shape (Callon 1998; 2007; Hacking, 1983; Jasanoff, 2004). To justify and enact colonial modernity's concentrations of power and privilege (see section 1.2.3, Appropriating privileges), focal categories in modern knowledges can be ordered as (more or less) 'superior' and 'inferior' (Arora and Stirling 2023). This means that modern knowledge processes tend to not only foreground rigid categorical divides (as discussed in section 1.2.1, Hardening categories), but also stratify categories in starkly hierarchical orders. In these ways modern understandings treat large parts of the world – including entire cultures and diverse relations with 'nature' – as 'inferior' to those that are more privileged in colonial modernity. Resulting stratifying orders in modern knowledges rely typically on intersecting categories of species, landscapes, places, soils, race, religion, class, region, nationality, gender, ethnicity, caste, sexuality, 'humanity' and so on (eg: Arya 2020; Crenshaw 1991; Wekker, 2016).

Within modern sciences, such stratification is observed in the ostensible superiority of 'objective' natural sciences over more 'subjective' social sciences (Flyvbjerg, 2001). Stratifying orders might also manifest among different social sciences. For instance, by embracing closed quantitative approaches over more open qualitative narratives – and modelling themselves on what is perceived as 'hard' natural science (Mirowski 1989) – disciplines like economics can gain an air of authority and superiority over other social sciences.

Colonial-modern concentrations of power and privilege in the Global North mean that knowledges from Southern contexts may be considered as 'inferior' to Northern innovations of all kinds, including in the techno-sciences, social theory and philosophy (Dabashi 2015; Grosfoguel, 2013). Such stratification can reproduce developmentalist ladders of colonial modernity (Arora and Stirling 2023), according to which formerly colonised countries are slotted under stratified categories such as underdeveloped or developing. This ordering of countries is then used to assume global ambition for innovations sold/transferred by 'developed' countries of the North (Canfield, 2023; Jasanoff, 2006), which others must adopt to 'catch up' (eg: Fagerberg and Verspagen, 2020). In more measured perspectives on innovations, unlike Northern products that are claimed to be 'high-tech', innovation patterns in the Global South may be diversely valued as frugal, grassroots, and induced by conditions of scarcity (eg: Srinivas and Sutz 2008; Sutz 2023).

Stratifying orders may also be framed using rankings on classifications in 'nature' (that is categorically bordered away from cultures). For instance, certain species may be considered as superior using ideas such as 'higher organisms', 'keystone species', 'dominant species', 'ecological engineer' or 'foundation species' (Cottee-Jones and Whittaker, 2012; Mills et al. 1993; Valls et al. 2015). Using such hierarchical ordering, 'superiorised' species may be considered as crucially worth protecting through biodiversity conservation efforts (Stokes 2007). At times the rationale for protection may be based on whether a species is seen as *sitting on top* of a 'food web' or considered more aesthetically pleasing and charismatic or otherwise more important than others in a community of species (eg: Lorimer, 2007).

Arguably stratifying orders are most prone to extreme violence where they are made to manifest through "constructed categories of social difference" (Behm et al., 2020). While cultural heterogeneities are considered crucial for creative inspiration and innovation (Chua, 2018; Arora 2019), stratifying orders can turn those differences into political "struggles for hegemony" (Kalt, 2024). In some such struggles, extreme violence can be inflicted through hierarchical orders of racism, sexism, casteism, nationalism and Islamophobia, as is indeed all too sadly clear to see in policing and militarism around the world (Nwakanma, 2022). Through such ordering, 'superiorised' entities are apparently granted the license to control those positioned on other sides of colonial modernity's rigid categorical divides (see sections 1.2.1, Hardening categories and 1.2.4, Controlling objectivity). Social-ecological control may then be imagined and aimed not just through physical barriers and apartheid walls, but also through digital innovations like artificial intelligence (AI) into which racism and coloniality may be inscribed (Arora and Stirling 2023; Birhane 2020).

For example in digitising cities, stratifying orders promote modern innovations that are driven by 'big data' and by instrumental rational approaches to understanding and managing cities (see examples from Dutch cities in Bunders and Varró 2019). Such 'high-tech' innovations are preferred over many local-urban artisanal ingenuities and living practices (Arora 2016; Dameri 2013). In

this way, a multiplicity of ways of approaching 'smart urbanism' (including approaches to improve living conditions for people with disabilities: Makkonen and Inkinen 2024) are suppressed under a dominant tech-driven vision of urban growth and 'sustainable' prosperity. In such colonial-modern visions, even biodiversities are placed in the lower orders as compared to (gamification in) AI-powered smart city systems (dos Santos et al. 2025). Where urban 'nature' is brought into the picture, it is 'programmed' as green infrastructure to support the provisioning of recreational parks and reduced air pollution for the privileged (Gabrys 2022; Hui et al. 2023). At the same time, smart citizens are configured by concentrated power and privilege driving digital technologies: for instance, to participate in ceremonial consultations where agendas are pre-set for the adoption of new technocratic modes of economic activities and forms of socio-political life (Cardullo and Kitchin, 2019; Ghosh and Arora, 2022).

Decolonial struggles here involve resistance against stratifying orders like racism, sexism and casteism, as they are built into modern science, technology and wider cultures. This may involve *refusing* specific innovations such as agricultural biotechnology, smart cities and artificial intelligence where such stratifications are materialised (Arora et al. 2020; Tacheva and Ramasubramanian, 2023). Decolonial struggles also involve considerations of equality and epistemic justice towards Southern innovations classified as frugal, informal, social, grassroots and so on. Taking such diversity of innovations seriously in relational terms, means that no further normative assessment based on standardised criteria can be applied (see section 1.2.7, Standardising practices). Decolonising innovation processes may thus require the breaking of equations that treat fast as efficient, digital as smart, industrialisation as growth, and old as obsolete. By embracing a multiplicity of (egalitarian) orders, it may become possible to appreciate techno-scientific progress in diverse shapes and forms beyond colonial modernity.

1.2.3. Appropriating privileges

Colonial modernity's stratified orders between the Global North and South mean that a key epistemic privilege is exercised through Northern scientists and inventors – across public institutions and private organisations – claiming ownership of knowledge as "intellectual property". This means that the agency of a wider range of less privileged actors is either suppressed in or excluded from processes of developing innovations. At the same time, concentrated power and privilege can lead to 'epistemic colonialism' by the Global North, from where the presumed authority of scholars and the inflated promise of their innovations are transmitted to the world at large (Ghosh et al. 2021; Stone-Mediatore, 2018).

Appropriation of economic privileges for their concentration in metropolitan regions around the world, may also be enacted through 'unequal exchange' (Hickel et al. 2021). This represents 'hidden transfer of value' that is not accounted through (depressed) wages paid to labour and prices of traded knowledge-based goods, particularly from the Global South to the North. Similarly unequal exchange can be constitutive of urban centres of privilege within and between Southern countries and regions, based on hidden transfer of value from rural areas and from low-waged workers. Resulting concentrations of wealth and income are *intersectional*, compounding across social stratifications based on race, gender, class, caste, ethnicity, religion and more (see Section 1.2.2, Stratifying orders). While transition scholars have started examining the unjust effects of intersectional disparities (Johnson et al. 2020; Walk 2024), much more research is required to grasp relations between intersectional oppressions (particularly those involving racism and casteism) and struggles for epistemic justice in sustainability transitions across different contexts.

To further unpack intersectional injustices, it may be useful to pay attention to the *infra-sectional* ways in which each category – defined and settled in terms of gender, caste, race, ethnicity, religion and indeed class – is constituted from within by a wide variety of relations that extend far beyond all given categorical boundaries. This immanence of boundary-spanning relations in constituting a defined category, is what Arora and Stirling (2023) proposed to conceptualise as 'infra-sectionality'. Perhaps this infra-sectionality is nowhere as clear to see as in the colonial-modern category of the 'human'. Immanent to the notionally singular 'humanity' of colonial modernity are not only immense inequalities, but also the constitution of those inequalities by relations of control and extraction with nonhumans in 'nature' (supported for instance, through their depiction as 'natural resources' or 'natural capital'). Modern nature is thus not the 'constitutive outside' of an unequal humanity (cf. Mitchell, 2000), as moderns claim it to be (through the hardening of borders between categories: sections 1.2.1, Hardening categories and 1.2.8, Singularising ontology). Instead when approached relationally, 'nature' is constitutively inside modern human cultures and vice versa. For taking this mutual constitution seriously, we use the term 'worlds' to describe modern and other plural nature-cultures in section 1.2.9 (Dominating worlds).

It is through immense concentrations of epistemic and financial privileges in the Global North – often in some of the world's largest tech corporations – and their allies in the South that imaginations of smart cities centred on digital technologies are developed and promoted (Sadowski and Bendor 2019). Within tech corporations, particularly in the North, issues of white (and brown) masculine domination have been widely documented too (eg: Daniels 2015; Reitman 2006).

Local appropriations of privileges within 'smart cities' can be enacted through ownership of properties in "gated communities" (Roy 2011). In India, intersections between caste and gender are seen as centrally constitutive of such appropriation of privileges (Basu 2019). They also extend digital divides and facilitate extraction from marginalised communities (who may have lived on the land that is used to build smartness (Lara et al. 2016)). Similar colonial-modern relations are extended with 'nature' in the production of digital innovations that underpin smart cities, through the extraction of a wide range of rare earth metals and vast amounts of energy (Dutta 2018; Mishra and Singh 2023).

Decolonial struggles against appropriation of privileges involve challenges to the assumptions that knowledge is to be owned and nature is to be controlled. Colonially appropriated and extracted economic privileges can be mitigated through reparations (Walker 2016; Táíwò, 2022). Appropriated epistemic privileges centering Europeans, on the other hand, may be tackled by highlighting everyday innovations developed through "creative activities" of ordinary people in Africa and other parts of the Global South (eg: Mavhunga 2014). Decolonising innovation may also involve methods such as 'participatory action research' where knowledge is carefully co-produced with, for and among infra-sectionally marginalised communities (Mason 2015). Such attempts to realise

epistemic justice not only help dismantle colonial modern hegemonies in knowing and learning, they can also foreground decolonial routes to sustainability transitions grounded in *many worlds* beyond modernity's categorical divides and stratifications (Arora and Stirling 2023). To transform colonial-modern infrastructures in smart cities and further afield, decolonial social movements can be central to countering gendered racial, casteist, ethnic, classist, and religious exclusions. To go beyond colonial modern infrastructures, it may be crucial to engage with calls for 'pluriversal urbanisms' (Moreno-Tabarez et al. 2023), as we discuss further in section 1.2.9 (Dominating worlds).

1.2.4. Controlling objectivity

Foundations of colonial-modern innovation processes – of categorisation, stratification and appropriation (as discussed above) – hold particular implications for how wider realities are addressed. As they are categorically bounded away from cultures and considered as parts of nature, ecologies are also objectified. This objectification takes place through a distinctive blindness of colonial-modern innovation patterns to multiplicities of manifestations of nonhuman sentience, learning, intentionality, subjectivity, normativity, emotion, affect and agency. In short, barring some recent disruptive developments in disciplines such as botany and ethology (eg: Despret 2008; Gagliano et al. 2016), colonial-modern innovations tend to obscure all kinds of material-symbolic agency of nonhuman ecologies.

As a result – even (for instance) in environmentally critical approaches of 'the Anthropocene' – planetary 'nature' and its myriad constituting aspects are treated as objects lacking agency that is itself assumed to be a preserve solely of modern humans (Arora et al. 2020). Such treatments are useful in highly reductive and deterministic ways to *claim universal objectivity* for modern natural sciences, with little recognition of relations between what is understood and who does the understanding. The contents of knowledge tend to be treated purely as if they are representations of whatever is 'the object' (see section 1.2.5, Reifying representations), rather than as also being shaped by attributes of the (social-political) subject doing the knowing. Such forms of controlling objectification thus neglect that the substantive content of knowledge is always jointly shaped by connected circumstances and histories of what moderns categorically separate as 'objects' and 'subjects' (Haraway 1991).

Controlling objectivity also means the neglect of much richer registers of formativity, autonomy, cognition and emergent politics associated with 'natural' worlds (Bennett, 2010; Kohn, 2013). For example all that might otherwise be sentient and spiritual in wider worlds, is encountered in colonial modernity as objectified through deterministic instrumentalised machine-like imaginations of control (Stirling, 2019). So physics reduces to (quantum) mechanics, chemistry to (toxic) industry, biology to (genomic) biotechnology, agroecologies to (productivist) agronomies, and meaning itself to (discrete) digits.

In this way, an overarching imaginary of control is made hegemonic in innovation governance, but kept invisible at the same time. Fallacies, flaws and (sometimes catastrophic) error-proneness of control are obscured. While control's machine-like imagination does inevitably break down, it can be sustained incrementally by ever-desired appropriations and extractions for concentrating privileges (section 1.2.3, Appropriating privileges). Denials of breakdowns are also afforded by externalising uncertainties and other adversities associated with real-world indeterminacies (Stirling, 2015), while intersectionally oppressed human beings and diverse nonhuman relations are rendered by objectification into targets of control and domination (Arora and Stirling 2023).

Technological examples of controlling objectivity can again be found in agricultural genetics. Wherever complex relational ecologies are objectified into categorically individualised 'genes' within notionally orderly 'genomes', control is imagined in ostensible correspondence in simple one-to-one mappings onto socially desired categories of functionality (section 1.2.1, Hardening categories). This is then used to suggest that phenotypic lineages are closed and deterministic rather than open, uncertain, and context-interactive (section 1.2.5, Reifying representations). Diverse complex metabolisms in relation to seeds, for example, are simplified into objectively identical organisms. Entire social and natural landscapes of cultivation are then seen as smoothly 'scaling up' from instrumentally favoured genetically modified seeds that objectify ecologies in their design and wider use. So what are in fact radically complex, messy, diverse and indeterminately interacting agronomies, cultures and ecologies are homogenised, objectified and disciplined for imagined control in genetic engineering.

Finally objectified in this way, entire material and living worlds within which societal and technological change play out, are denied their own generative heterogeneities. Thus, pluralities are reduced, connectivities suppressed, encompassing contexts sidelined and embodied qualities deleted. Diversities of nonhuman sentience, agency and affect are all systematically denied.

This objectification of realities by colonial modernity can be countered in **decolonial struggle** through deliberate forms of collective action aimed at disrupting practices that obscure (diversities of) nonhuman agency. This might require: a) recognising sentience, affect, and intentionality in a wide range of ecological entities and wider processes; b) rebuilding relational patterns involving cultures, through which different kinds of nonhuman knowledges and agencies are constituted; and c) re-asserting embodiment that considers deeper and more generally constituting relations inherent to worlds as natural-cultural wholes. Beyond living metabolisms, individual organisms, nonhuman communities, unfolding ecosystems, and evolutionary dynamics, a wider range of earthly processes may then be foregrounded. In these, cultures and natures are entangled in radically diverse ways in the making of many worlds.

1.2.5. Reifying representations

As just discussed, in colonial-modern innovation processes, nonhuman sentience, cognition, intentionality, emotions and relational agency are often overlooked. This oversight paves the way for *reification* of modern knowledges in innovations. Reification means that known quantities and qualities of things – in numbers and words – are overblown to be considered as *actual worlds*. Thus what is grasped by moderns as their science or knowledge, is equated with reality itself through reification.

Such reifying representations are particularly prevalent in scientific knowledge produced by large corporations and in evidence

that is instrumentally mobilised for policy (eg: about purported benefits of genetically modified crops). Through such representations in markets and policies, behaviour of consumers and citizens is imagined as managed through the presumed authority of complete facts and associated technologies. In this process, incompleteness of all knowledge that is made to count as fact or evidence, and uncertainties associated therewith, are widely suppressed (Arora, 2019; Stirling and Scoones, 2020). Real worlds are thus *concretised* in/as ostensibly objective modern knowledges (section 1.2.4, Controlling objectivity). This concretisation is also deployed to assert the supremacy of modern techno-sciences over colonially marginalised ways of knowing (Arora and Stirling 2023), as further discussed in section 1.2.9 (Dominating worlds). These ways of knowing are often associated with Indigenous and other colonially oppressed artisanal communities around the world.

It is already observed above that in genetic engineering for agriculture, rigidly fixed categories such as genes and DNA/RNA molecules are privileged over multitudes of socio-ecological relations that constitute a target species (Fox Keller, 2000). In reifying representations produced by genetic engineers, subjectivity of scientists and the powerful interests that govern their practices are generally obscured, while genes and molecules are approached as stable objects that can be precisely controlled in genetic modification (Arora et al., 2020; Stirling, 2019; Shah et al. 2021). Far from being modern biological constructs that are always uncertain and ambiguous, genes and molecules are thus reified as concretely real entities that are considered amenable to precise control. *Suppression of uncertainties* in such ways helps justify incumbent categorical separations of natures from cultures, subjects from objects (sections 1.2.1, Hardening categories and 1.2.4, Controlling objectivity). Suppression of uncertainties also helps obscure colonially appropriated concentrations of privileged interests driving genetic engineering in agriculture (Jasanoff 2006; Arora et al. 2020), which have helped raise a globalised industry around biotechnology.

The recent discourse around genetic engineering innovations for biofortification of food crops is illustrative here. Biofortification is widely promoted to address issues of poverty (and its correlate of low-nutrition diets) and the decline in nutritious quality of food in recent decades (ostensibly due to land degradation and climate change) (see Kathi et al. 2024). Most biofortified crops such as orange sweet potato (with provitamin A) and zinc rice are currently cultivated in the Global South. Apart from a few examples like transgenic 'Golden Rice' (Glover and Poole 2019), these crops have been developed using conventional breeding techniques. Promoters of genetic engineering for biofortification claim several advantages over conventional breeding that has focused on increasing just one nutrient such as iron or zinc in a crop. Claimed advantages of genetic engineering include simultaneous increase of multiple nutrients in a single crop, along with modification for other agronomic traits like high yields and drought-resistance; as well as shortening the time required (to much less than the 8–10 years for conventional breeding) for developing and releasing newly fortified varieties (eg: van der Straeten et al. 2020).

In promoting genetic engineering for biofortification, it is assumed that 'increased nutrients' and their post-harvest stabilisation as intended by genetic manipulation, are indeed fully realised in actual practice. In such promotions, uncertainties inherent to the genetic techno-sciences for biofortification are marginalised. Such uncertainties have been recognised elsewhere, for instance, in relation to CRISPR genome editing technology that leads to 'unwanted mutations' in non-targeted parts of DNA (Hahn and Nekrasov 2019; Shah et al. 2021). Availability of data about such 'off-target effects' is limited for novel genome-edited biofortified plants. Especially under such conditions of limited data, it is crucial to admit that uncertainties associated with plant genetic modification are unavoidable (Arora 2019). However, admittance of such uncertainties is largely missing in promotions of genetic engineering for biofortification. Uncertainties are either downplayed as manageable risks or downright occluded.

Reifying representations can be countered through **decolonial struggles** involving: a) shifting attention from readymade representations to the relational processes of knowledge production; b) in these processes focused on the doing of knowing, revealing how uncertainties are inherent so they can be openly admitted to wider publics; c) admitting uncertainties (eg: associated with genetic engineering) to help strengthen political solidarity with social movements that promote plural *agroecological alternatives*. It is in such movements that farmers can most effectively refuse genetic engineering (Arora and van Dyck 2021), and nurture other ways of knowing on farms and pastures, particularly those associated with colonially marginalised peoples (Arora et al., 2025). Crucial in such nurturing of plural ways of knowing across all kinds of skilled practices of making and doing, can be refusals of modernity's settled separations between representation and reality, knowing and making, growing and learning, as well as being and becoming. Foregrounded can then be the many ways in which being is becoming, growing is learning, knowing involves making (of equipment and artefacts), and representations play performative roles in reality – and vice versa – not just in modern worlds built through coloniality but also across other worlds that are damaged by the same coloniality (Arora and Stirling 2023).

1.2.6. Monopolising quantifications

With human and nonhuman worlds so forcefully categorised, stratified, appropriated, objectified and reified as detailed above, epistemic and ontological foundations of colonial-modern innovations are further enacted through even more restrictive performances of quantification. In particular, moderns seek to fully characterise complex context-dependent qualities using apparently context-free scalar numbers. This monopolising quantification has the effect of buttressing reifying representations of transcendent objectivity (see sections 1.2.4, Controlling objectivity and 1.2.5, Reifying representations).

Through monopolising quantification, powerful interests and privileged agents in colonial modernity are able to establish deeper and more comprehensive forms of legitimation for their favoured kinds of understandings and associated social-material action. The invoking of principles, practices and institutions of 'mathematical rigour' that are especially aggrandised in colonial-modern governance and academic settings, helps *entrench* both general structures of privilege and power as well as more specific justifications for particular interventions (like promoted technologies, infrastructures and policies). Through modern quantification, then, multiple stratifying orders (e.g., around race, gender and caste: section 1.2.2) are made commensurable with each other. This commensurability allows (quantifying) aggregation to be enacted across multiple stratified orders, rather than just one, and legitimizes the

monopolization of social choice in modern governance and academic settings.

In this process, the multiplicities of dimensions that can inhere in objectified categories are first assumed to be broadly comparable and thereby rendered commensurable. They are then subjected to ordinal orderings, followed by cardinal orderings. Each constituting dimension is thereafter reductively assigned a presumably complete and definitive number scale (that is considered distinctive to the particular dimension). In this way, modern arithmetic disciplines allow performance of highly constrictive kinds of aggregation, in which the radical multiplicities of possible relative scalings, weightings and functional forms are typically reduced to simple scalar coefficients (Stirling and Coburn 2014). The ostensible purpose of such a process is gaining authority for whatever aggregated number contingently emerges from the arithmetic. These reductive, aggregative practices of quantification further consolidate a worldview in which unruly multiplicities of relations – including between 'objects' and 'subjects' of knowledge production – are either widely obscured or reduced (and reified) into apparently more settled, well-bounded and precisely-determined schemes (Stirling 2023).

With respect to genetic modification technologies already discussed, these distinctive characteristics of quantification are perhaps most obviously illustrated (and strongly asserted in real-world governance) in the globally powerfully mandated disciplines of risk assessment. Enforced by international law through bodies like the World Trade Organisation, genetically modified plants, animals and wider organisms often form the centrepiece of a variety of business models and trading arrangements designed to maximise extraction and accumulation through the appropriation of intellectual property in formatively constituting 'genes'.

By these means, genetic technologies' potential positive and negative implications for people, societies, fellow beings and encompassing environments are then themselves tightly engineered through processes of reduction and aggregation outlined above – applied prominently in both 'probability' and 'magnitude' dimensions of risk (Callon et al. 2009). Amplified by wider institutionalisation of statistics, accounting and probabilistic methods, the result is a reductive imposition of mathematical authority around 'science-based assessment', 'risk-based decisions', 'evidence-based policy', 'data-smart innovation' and so on.

To resist colonial-modern processes of quantification, each step can be disrupted or impeded by **decolonial struggles**. As arithmetic idioms, mathematical understandings and quantitative practices can be entirely legitimate and highly efficacious in appropriate settings, decolonial struggle can focus not so much on denigrating or excluding quantification as a whole, but in demonstrating and highlighting the many concealed and highly political contingencies associated with modern quantification. The point is not to throw the quantitative baby out with the justificatory bathwater, but to clearly emphasise that – when subordinated instrumentally in the ways described here, these quantitative practices are actually often deeply lacking in precisely the kinds of rigour on which their exaggerated authority is held to rest. The challenge therefore extends to decolonial emancipation of diverse Indigenous and artisanal traditions of quantification themselves (in many worlds beyond colonial modernity: see sections 1.2.8, Singularising ontology and 1.2.9, Dominating worlds), rather than wholesale rejection of all quantification.

For instance, **decolonial** sensitivities to ontological differences can be respected by greater emphasis of disaggregative than aggregative quantification, opening up diversity through the use of vectors, matrices and tensors to consider irreducible pluralities of perspectives, dimensions and contexts (eg: Arora, Narayanarao et al. 2025). Sensitivity analyses can also help enact more humility in colonial-modern scientific claims. All of this might mean decolonial acknowledgement of socio-cultural and political differences as deeply topological rather than aggregatively geometric (Arora and Stirling, 2025, forthcoming).

1.2.7. Standardising practices

Standardisation is a key tenet of industrial production in colonial modernity. Both in modern engineering disciplines and in policy implementation, technologies and infrastructures are imagined and monitored as following certain standards and uniform regulations. For instance, electric vehicles employ standards for charging, grid integration and safety (Das et al., 2020). Inside factories, at least since the rise of Fordism, historians have observed how standardisation of production machinery and product components has not only led to deskilling and control of workers on assembly lines, it has also further concentrated power and privilege for managers and capitalists (eg: Hounshell, 1984; Noble 2011; Sanchez 2012).

Colonial-modern standardisation extends far beyond the production of uniformities and homogeneities in engineering and industrial production (Yates and Murphy, 2019). Laws, protocols and conventions widely structure social practices – shaping how individuals and collectives enact and imagine political lives (Dutta, 2015). What became new norms and standards under colonial oppression were used by European colonisers to control (resisting) populations. In 'postcolonial' countries like India and Nigeria, many colonial laws continue to be enacted today. Similarly, infrastructure codes and regulations remain stuck and 'contaminated' in red-tape bureaucracies designed by former colonisers (McFarlane, 2008; Naseer, 2018; Olajide et al., 2018). Through such standards, codes and laws, cultures and values have been targeted for change, often without attempts to better embed standards, codes and laws within diverse local contexts (Carvalho and Lazzerini, 2018).

Colonial modernity has by now enacted standardising practices in nearly every area of activity, from agriculture and energy to transport and education. In relation to *knowledge production* in modern academia, activities like publishing in journals and presenting research to academic peers in conferences are now standard practice, which are predominantly used to measure success rather than participatory action research with/in marginalised communities (Cornish et al. 2023). In *governance practices*, administrative values like public service delivery and trust may be standardised through typologies and ideal types (Goodsell 2006; Wittman et al. 2021), which may eventually be very rarely followed in practice. Even innovations, niches and solutions when evaluated as successful, may be 'scaled up' as standards for communities elsewhere to follow, rather than promoting the development of communities' own resilience through 'everyday local struggles' (Ghosh et al. 2021). In these ways, standardising practices can obscure or marginalise flourishing diversities of knowing, governing and being across different situated and connected contexts.

Standardising practises are widespread in smart cities. They are often imposed on aspiring cities as a 'global order' such as a smart traffic system, smart security system, and smart waste, water and energy systems (Hayat, 2016). Data-driven governance', 'bike

sharing schemes', and smart citizenship models are often pursued as innovative solutions on the basis of restrictive understandings of how people (can) behave and live (Kumar, 2017; Dutta, 2018). A key instance of standardised practices in governance, is the elimination of 'informal' spaces, networks and exchanges through authoritarian smart urbanism that considers longstanding and vital service provisioning as "increasing *menace of encroachment* of roadside public places by hawkers," and as "*hampering free flow* of traffic in service roads" (Ghosh and Arora 2022: 326). Using such negative tropes, livelihoods and ways of living of underprivileged citizens are powerfully suppressed in quests for globally acceptable, colonial standards of smartness that channels and refreshes historic pressures of formalising innovation and governance within colonial modernity (Olajide, 2025; Kütting and Godek, 2025).

Decolonial struggles to counter standardising one-size-fits-all 'scaling-up' of innovation patterns, might involve the foregrounding of contextually diverse innovative practices. Rather than extracting insights from such contextualised practices for the 'global good' of sustainability transitions, decolonising transdisciplinary research can enable local autonomy over knowledge production and use. More than adopting or adapting 'innovations from elsewhere', decolonial knowledge autonomy means that marginalised ways of knowing are empowered to nurture their own innovations. Supporting such not-so-dominant yet convivial practices is crucial today as eco-modernist technocratic 'solutions' appear to have become hegemonic around the world as anchors for sustainability transitions (Arora et al. 2020). Ultimately decolonising efforts may involve support for a diversity of scientific and engineering methods and the promotion of multiple locally situated standards of policies and practices for empowering the marginalised in 'a world in which many worlds flourish together in divergence' (Arora and Stirling, 2023).

1.2.8. Singularising ontology

Enactments of the colonial-modern assumption of a "one-world world" (Law 2015; Blaser and Jensen, 2023), produce effects that are ontologically deeper and more extensive than attempted standardisation of different production and governance practices. Underpinned by this assumption, plural realities associated with diverse ways of living and knowing on Earth, are approached as a single reality that is captured by 'universalising' modern science. In this singularisation of plural realities, colonial-modern ontological separation of 'objectified nature' from 'subjects in cultures' is enacted (see section 1.2.1, Hardening categories), as multiple ontologies associated with the Earth's diverse ways of living and knowing are neglected or obscured.

These ontologies are often associated with ways of knowing practised by colonially marginalised artisans, agroecological smallholders and Indigenous peoples (Blaser 2009; Arora 2019). They are sometimes collectively classified as *relational ontologies* because they consider as central the flowing interconnectedness between natures and cultures (eg: Escobar 2018). They may also admit the coexistence of more-than-human cultures, communities, sentience, spirituality, affect, wisdom, learning and wider agency.

Given that colonial modernity spans most if not all nation-states in the world today, the obscuring of plural ontologies paves the way for refashioning of cultural-natural relations that constitute Indigenous and otherwise oppressed ways of knowing, into objectified resources for extractive modernisation (section 1.2.4, Controlling objectivity). Through such modernisation then, oppressed and Indigenous ways of knowing are either marginalised by or integrated into modern innovations. This integrative imagination can re-enact models of colonial assimilation across postcolonial societies undergoing 'development' and 'growth', which are also prevalent across settler societies like USA and Australia (Todd, 2017; Arora and Stirling 2023). The same integrative imagination can re-present diverse political assemblages of knowing and making constituted by plural ontologies, as (grassroots) "innovation ecosystems" with interacting components (including technologies, actors and institutions), within and across modern nation-states (eg: Wierenga, 2025).

In recent discussions on developing climate resilience, agricultural biotechnology innovations have been widely promoted. Research has highlighted genetic engineering's potential for realising a range of successes including plants adapting to biotic and abiotic stresses, improving efficiency of CO_2 fixing, and increasing genetic diversity (eg: Ammar et al. 2024; Garland and Curry 2022; Patil et al. 2021; Saad et al. 2022; Zafar et al. 2022). In such discussions, genetic modification for developing 'climate resilient' varieties may be considered as an innovative advance not only over conventional breeding but also over seed saving and sharing by (agroecological) farmers around the world over thousands of years. Farming communities' seed development practices across diverse oppressed and Indigenous agroecological contexts are thus taken to be underpinned by the same ontology as modern seed breeding using genetic modification. This assumption obscures plural ontologies and marginalises diverse agroecological alternatives to colonial-modern ways of knowing in climate resilience and agricultural sustainability (Ajwang et al. 2023).

At the same time, a multiplicity of germplasms sustained by colonially oppressed – artisanal, Afro-descendant, Maroon, Adivasi, Dalit and Indigenous – farming communities may be appropriated for integration into modern agricultural knowledge and innovation systems, to serve as bases for producing genetically modified seeds by private corporations and public institutions (Section 1.2.3, Appropriating privileges). Progressive appropriation, integration and exclusion of ontological diversity by colonial modernity means that plural agroecologies are subsumed by industrial agriculture (Arora and van Dyck 2021). Through such subsumption, colonial modernity damages and destroys other agrarian worlds constituted by relational ontologies (and the ways of knowing associated with them).

Decolonial struggles here point to the embracing of plural ontologies (Arora and Stirling, 2020). In the first instance, this requires recognising that any entity or wider realities can be known differently depending on how they are *approached* – for example, to direct control at them, or practice care and nurture hopes of conviviality with them (Arora et al. 2020). Deeper, more radical differences in plural realities can be recognised if underlying ontologies constituting diverse ways of knowing are taken seriously. Recognition of plural ontologies highlights that decoloniality involves struggles not only for restorative justice to establish racialised and colonised peoples' gendered rights and autonomies (over their lands, labour and cultural knowledges), but also for the flourishing of multiple relational ontologies that underpin peoples' diverse ways of knowing with/in many political ecologies. However, rather than treating each such ontology as unique and essential to one Indigenous (or otherwise oppressed) community and way of knowing, decolonial

struggles foreground *pluriversal conviviality* between radically different ontologies that underpin ways of knowing and doing for being and becoming beyond colonial modernity (as further discussed below). It is through decolonial struggles for convivial relations that non-modern worlds continue to coexist and diverge from each other.

1.2.9. Dominating worlds

Acute concentration and accumulation of economic, cultural and epistemic privileges in the hands of some Europeans and other moderns, means that such privileges can be deployed to incentivise those innovations that help build colonial-modern worlds. Such innovations include agricultural genetic engineering and digital cities that we have focused on. The worlds made through modern innovations manifest in a wide range of alternative forms around the world (cf. Gaonkar 2001), and the societies they constitute may be considered patriarchal-nationalist and capitalist-transnational in a variety of ways (Hall and Soskice 2001; Sarkar, 2021).

Across different forms, what makes such worlds colonial-modern is their shared enactments of ontological divides discussed earlier (sections 1.2.1, Hardening categories, and 1.2.4, Controlling objectivity). Directly associated and equally constitutive of disparate colonial modernities are 'assertions of military supremacy' and 'extensions of toxic extraction' (Arora and Stirling 2023). It is through such constituting processes that colonial modernities in their different forms, end up violently inflicting *damage and destruction on many worlds* built through marginalised ways of knowing associated with diverse oppressed peoples (who may be minoritised in modern nation-states on the basis of race, religion and/or ethnicity). Equally, it is through centuries of anticolonial resistance and decolonial refusal (Brown 2020; Diouf 2014; Simpson, 2014), that these many worlds have constituted and sustained a pluriverse on Earth despite the immense growth and dominating impact of colonial modernities (Arora and Stirling 2023; de la Cadena and Blaser 2018).

Arguably such domination by colonial modernities over other worldmakings is intensely hegemonic in smart city imaginaries (Miller 2020). A colonial-modern city with its unjust authoritarian infrastructures such as highway corridors built through dispossession of agrarian lands and displacement of marginalised peoples (Bathla 2025), and exploitative and biased digital platforms for provisioning basic urban services (Rosol and Blue 2022), are widely accepted ways in which the present and future of cities is understood and imagined globally. Smart cities extend this technocratic imagination through intelligent systems for traffic management, data-driven e-governance, gated communities with optical broadband connectivity, and facial recognition softwares for 'security' and ostensibly 'e-democracy' (Kumar 2017; Leszczynski 2016). Such smart urbanisms are now increasingly seen as morphing into 'autonomous and self-learning cities' powered more fully by artificial intelligence (Norman 2018; Cugurullo et al. 2024; Luusua et al. 2023). These AI-powered smart urban futures are promoted by transnational financial and industrial capital and commercial management consultancies (Sadowski and Bendor, 2019). Widely neglected and even demonised in smart city discourses are the worldmaking capacities of structurally oppressed and Indigenous peoples' urbanisms that may embed coexistence and care towards local climates, topographies, and artisanal traditions (Heckenberger et al. 2008; Arora 2016; Baweja 2022). Obsessed with hyper modern worldmaking through the digital, the thrust for narrowly defined smartness thus continues the colonial destruction of cities worldwide from Tenochtitlan (in 16th century Mexico) to Benin City (in early 20th century Nigeria) and beyond, while damaging possibilities for 'pluriversal urbanisms' to flourish (Lara et al. 2016; Moreno-Tabarez et al. 2023).

Decolonial struggles here foreground many actually existing and clearly possible earthly worlds. These worlds may be constituted

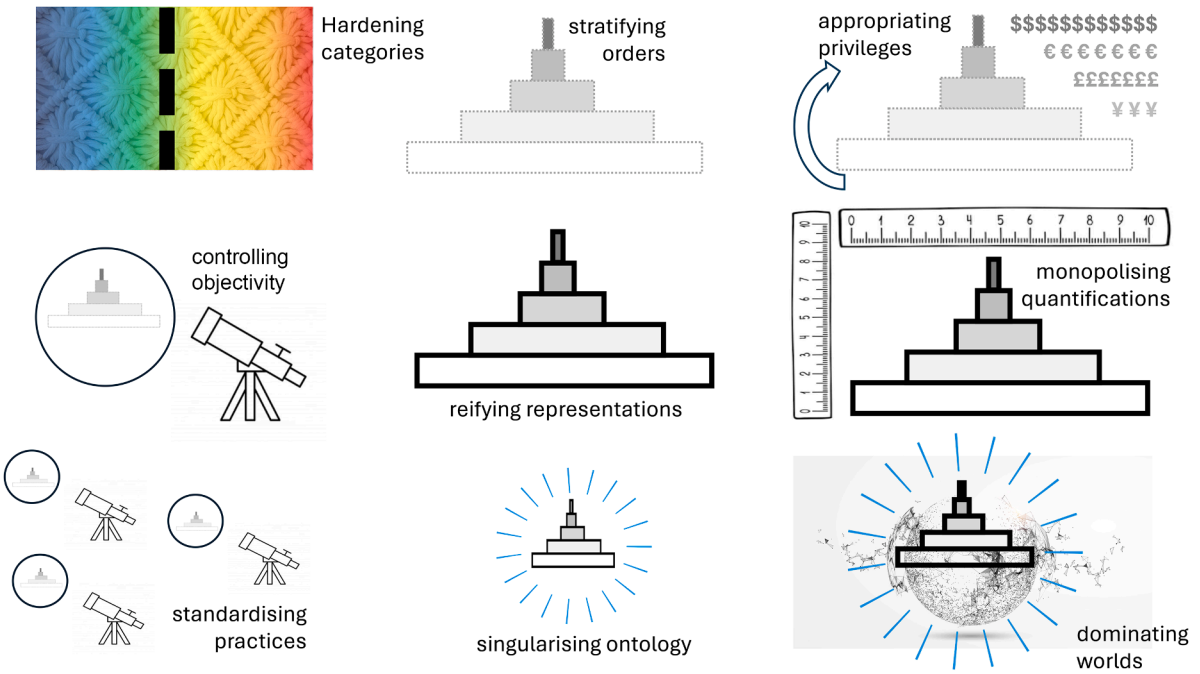

Figure 1. A visual depiction of colonial-modern innovations' epistemological and ontological foundations.

by convivial and egalitarian relations between urban and rural living, between artisanal and agroecological practices, as well as between forests and infrastructures. Such relations enable decolonial refusals and anticolonial resistance for either radically transforming or carefully dismantling colonial modernities, so that many worlds can coexist and thrive in the world.

Crucial for such thriving are **decolonial struggles** that refuse and resist modern industrial worldmaking across cities and villages (Kothari et al. 2019). Such movements may also aim for the reduction and degrowth of colonial-modern economies towards many alternative forms of collective spiritual growths and prosperities (Arora and Stirling 2021). Decolonial struggles thus underscore the importance of pluriversal reparative justice (Arora, Kpodonu et al. 2025): for the flourishing of relational autonomies of oppressed and Indigenous peoples' and nonhuman relations' worldmaking of many kinds – spanning rural areas where pluriversal agroecologies are damaged by modern techno-scientific innovations like genetic engineering and in urban areas where digital smartness harms possibilities of pluriversal cities.

2. Conclusions

The nine interwoven foundations articulated above are visually depicted in Figure 1. The foundations do not offer an exhaustive account of colonial injustices associated with modern innovations. As discussed, they are informed by disparate bodies of related work, and illustrated using the two cases of smart urbanism and genetic engineering in agriculture, to offer a contingent weave of concepts for onward analysis and wider political struggle.

Taken together in some (partial) combination, the nine foundations highlight imperatives and opportunities to decolonise modern innovation patterns by:

- *confronting colonial concentrations of power and privilege* as they are embedded into modern innovation processes (in order to directly address constituting social-ecological injustices associated with colonial-modern innovations);
- *extending egalitarianisms* (towards racially and otherwise intersectionally marginalised contributors to knowledge production);
- *embracing uncertainties* in all that can be known or made (in the hope that decisions for actions are suffused with humility and care towards the marginalised in all proximal and distal contexts);
- *grasping encompassment* (by wider material and living ecologies of all that is notionally separated as 'human' or 'nonhuman');
- *admitting open-pluralities* of qualities across all innovation processes (and their constituent relations as well as in dimensions of polythetic categories outlined in section 1.2.1); and
- solidarity with struggles for *pluriversal reparations* to dismantle colonial relations between modern and other worlds (Arora, Kpodonu et al. 2025): to support flourishing relational autonomies of many incommensurable ways of knowing-being liberated from colonial modernity's 'one-world world'.

In these ways, we argue that insights on innovation patterns in sustainability transitions can help support wider decolonial transformations for (shrinking) modern worlds, in solidarity with Indigenous, Afro-descendant, Maroon, Adivasi, Australasian, and other colonially oppressed peoples' struggles for pluriversal justice. Both the critical diagnoses of colonial-modern innovation patterns and the imperatives and opportunities for decolonial struggles beyond those patterns, as elaborated above, are directly relevant to thinking and action that span modern separations of human wellbeing and ecological flourishing. They are also equally relevant to specific political-ecological transformations required in associated emerging institutions and practices.

Particular implications therefore arise for a core topic of this special issue around colonial-modern ideas of 'wellbeing' in sustainability transitions (Rauschmayer and Omann 2014). This is a somewhat under-scrutinised area in transition studies (Köhler et al 2019). Even where issues around wellbeing are attended to in this field, it follows from the pervasive hegemonies of colonial modernity that there is a tendency to treat wellbeing itself as social – *hardening categorical separation* from the ecological (rather than appreciating wellbeing as constituted by socio-ecological relational flows) (section 1.2.1) (Castellacci 2023). This applies equally across the full range of notions of wellbeing mentioned earlier, variously relating to distributive, procedural, recognitional and reparative justice. Such "misplaced concreteness" (Whitehead, 1978) about underlying categories can involve notions of wellbeing in transitions studies (as elsewhere) making use of narrow *reified representations*, that equate discourses to realities while suppressing associated uncertainties and ambiguities (section 1.2.5) (Rahman 2021). It is on this basis that attention often focuses on economistically *quantifying magnitudes* along predefined dimensions of wellbeing (section 1.2.6) (Forgeard et al 2011; Bautista et al 2023), which marginalise more open *pluralities of qualities* that can constitute wellbeing very differently across contrasting contexts (Fitoussi and Durand, 2018).

Beyond this, social wellbeing – whether seen to be associated with distributive, procedural, recognitional or reparative justice – is also often treated in a *hierarchically structured* fashion (Andresen et al 2000) – for instance helping further to elevate human over ecological aspects in transition studies (section 1.2.2) (O'Mahony 2022). Even where ecological aspects are explicitly addressed, the influence of prevailing instrumental framings like ecosystem services in understandings of wellbeing (Birkhofer et al 2015; Masterson et al 2019), can *objectify nonhuman ecologies* and erase appreciations for the multiplicity of associated entangled agencies – each one of which is not only a distinct site, but also an autonomous subject of well-being (section 1.2.4) (Summers et al 2012). Despite the progressive aspirations that typically motivate interests in wellbeing, this can inadvertently enact *appropriation and extraction of privileges*, which reinforce prior inequalities in ways that are all the more salient for being unintended (section 1.2.3) (Jackson et al 2022).

These tendencies can apply more directly, where concepts of wellbeing – like associated imaginaries and practices of justice – are *standardised* to fit with a controlling 'policy dashboard' common in transitions studies and beyond (section 1.2.7) (Durand, 2018). Such centralising tendencies are further intensified where wellbeing concepts are subject to a *singularising ontology* – obscuring or

assimilating diverse artisanal and/or Indigenous ways of enacting well-being (section 1.2.8) (Holst 2022; Carter and Andersen 2023). Although in many ways opposite to what is intended by proponents of modern wellbeing, then, these are examples of how prevailing gradients of power and privilege in colonial modernities can inadvertently and invisibly shape ostensibly progressive understandings, innovations or practices around wellbeing in sustainability transitions (Stirling 2019; Arora and Stirling 2023). Neglect for these dangers in areas like both sustainability transitions and wellbeing studies that are supposedly inherently resistant to coloniality, can make them more acutely susceptible to inadvertent capture by the core process of colonial modernity: *dominating worlds* through innovations that damage and destroy colonially marginalised lifeways (section 1.2.9) (Boodman 2023).

Finally, in the hope of nurturing onward decolonial struggles to transform or dismantle the core foundations of colonial modernity – for pluriversal justice and wellbeing, each of our arguments above can benefit from radical stories of decolonising innovation in which dissent (against controlling and extractivist designs of modernity), uncertainties, open-pluralities, encompassment, egalitarianisms and pluriversal reparations are embraced and sustained. Greater benefits might hopefully be realised through political ontological struggles for the flourishing of diverse enactments and conceptions of justice and wellbeing across many worlds. Making deeper relations with such enactments and conceptions, we leave for the future.

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