Received: 18 October 2023 | Accepted: 23 October 2023
DOI: 10.1002/eet.2079

RESEARCH ARTICLE

Environmental Policy and Governance
WILEY

# Cross-sectoral metrics as accountability tools for twin transitioning energy systems

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**Funding information**
Research Council of Norway, Grant/Award Numbers: 314022 (ASSET), 321421 (ROLES)

## Abstract

As energy systems become ever more closely intertwined in order to enable electrification and real-time coordination across sectors, tracking the nature of change to ensure accountability during complex implementation processes presents novel challenges and requires renewed thinking on data infrastructures. For instance, sectors like electricity generation, electricity distribution and electrified urban transport have begun to interact more closely and with more spatial complexity than ever before. Correspondingly, this conceptual article articulates the evolving relationship between cross-sectoral metrics (CSM) and twin transitions (i.e., digitalisation and decarbonisation) of energy systems in the Anthropocene. It argues for development of explicitly cross-sectoral metrical analysis as an accountability tool for shifts to equitable, low-carbon energy systems. It draws on three pertinent fields of study—calculative logics, institutionalisation, and degrees of digitalisation—to provide the basis for a theory of transformative metrics for application to evolving energy systems. Scholarship on calculative logics offers insights on the nature of metrics, work on institutionalisation helps understand the dynamics of integrating novel metrics into evolving socio-technical systems, and consideration of degrees of digitalisation ensures mindfulness of differences across contexts. Resulting insights can serve as diagnostic tools to inform timely monitoring and implementation of twin transitions for energy systems. Work across three distinct lines of scholarship is specified to enable conceptual development, and an empirical case study is sketched to show how to operationalise and apply an analytical framework. This delineation serves as a step towards a theory of transformative metrics, for integrative study of CSM for accountable twin transitions.

**KEYWORDS**
accountability, calculative logics, cross-sectoral, digitalisation, institutionalisation, metrics

## 1 | ACCOUNTABILITY, METRICS AND TWIN TRANSITIONS IN THE DIGITAL ANTHROPOCENE

To mitigate climate change stemming from excesses of human impact on nature in the Anthropocene era, commitment to ambitious low-carbon transition targets is increasingly accepted at multiple scales: national, regional and local. Through their National Energy and Climate Plans and the 'Fit for 55' climate package, European Union member states seek to more than *halve* greenhouse gas emissions by 2030 from a 1990 baseline, an ambition shared by thousands of cities under the Covenant of Mayors (Kona et al., 2018, 2021), and mirrored by many national targets (Hafner & Tagliapietra, 2020). Regulatory tools to orient action and monitor progress require metrics, defined as measurements privileged as standards (Sareen, 2020). Due to path dependency, these metrics remain confined to historically siloed sectors, for example, transport sector emissions per mode, or percentage of renewable energy content on the electric grid. But low-carbon transitions require infrastructural change, decarbonising electricity to electrify more sectors (Cooper, 2016), which necessitates digitalisation to integrate sectors and govern cross-sectoral energy systems (Duch-Brown & Rossetti, 2020). Cross-sectoral metrics (CSM) are thus key for so-called 'twin transitions' to digitalised and decarbonised energy systems. Yet energy transition policies today offer few examples of CSM. This opens up scope for an accountability gap, in the sense of publics being unable to hold those in power to account for meeting set targets (Fox, 2022). This gap must be addressed by developing CSM robust against the risks of accountability traps and selectively specified standards, which give the appearance but not the substance of accountability (Arnold, 2022; Park & Kramarz, 2019).

In energy social science, metrics matter as key enablers of changes in the institutions that govern the sociotechnical systems that must be transformed to meet the climate challenge (Hampton et al., 2021). These systems embody historical inequity: energy systems disproportionately benefit companies and burden vulnerable users, and transport infrastructures favour energy-intensive car users over public mobility (Johnson et al., 2020; Sareen, 2021). Inequitable sectoral metrics have led to many problems with low-carbon transitions, for example: 'enough is enough' protests against road tolls meant to limit car use in Norway (Wanvik & Haarstad, 2021); and initially controversial wind energy targets that burdened taxpayers in Portugal (Delicado et al., 2014). Any CSM that are institutionalised to become what I here term *transformative metrics* must ensure that rapid low-carbon transitions benefit wide sets of stakeholders. Else transitions may stall or exacerbate existing inequity. Thus, transformative metrics are accountability tools to ensure equitable low-carbon transitions, in response to the context of evolving energy systems with cross-sectoral coupling, defined as being institutionalised (i.e., adopted in practice) to assess change against envisioned baselines.

It is important to consider existing metrics, which are sector-specific, because what is measured at present is influenced by data availability and energy infrastructure, due to path dependence in systems of and approaches to categorisation (Bowker & Star, 2000). Take electricity. It has long been commodified, as something sold by large utilities and consumed by individual households or businesses (Daggett, 2019; Kale, 2014; Nye, 1992), but is also a basic energy service people have a right to access (Demski et al., 2019; Tully, 2006). Calculative logics vary over societies with diverse electricity needs (for irrigation, heating/cooling, lighting, to power specific devices), infrastructures (analogue or digital electric metres, high- or low-density distribution grids), and energy sources (coal-heavy base-load models, renewable energy and storage-enabled flexible electricity markets). With new renewable energy sources added at multiple scales, and sectors such as urban transport being newly electrified, calculative logics of multiple sectors intersect. Electricity bills become complex, linked with rhythms of fuel (electric transport charging) and energy generation (daily and annual profiles of increasing renewable sources like solar and wind energy; see, e.g., Bredvold & Inderberg, 2022; Powells & Fell, 2019). These sectors have had their own calculative logics. These are shifting, with dynamic tariffs on electric grids, grid interconnections that increase electricity market complexity, smart devices for users to automate electricity usage to charge electric cars, and increasingly coupled sectors where transport, domestic use and heavy industry all shape electricity demand. Electricity suppliers in turn make their tariff offers more differentiated to secure profits during complex sector coupling, governments set low-carbon transition targets and regulators design incentives and sanctions to steer development to these targets. Hence metrics are in flux, with equity effects at stake.

Energy metrics and infrastructure are deeply impacted by political considerations, which evolve over time (Moss, 2020; Sareen, 2020). For innovations like CSM to be mainstreamed, it is crucial to consider both their socio-political and techno-economic feasibility (Cherp et al., 2018), across sectors that are being integrated as energy systems digitalise in specific societal contexts. Digitalising complex systems offer scope for grave accountability gaps, as data infrastructures rapidly penetrate hitherto siloed sectors. The failed Sidewalk Labs in Toronto mark a famous example of resistance to such change, where Google's efforts to embed sensors ubiquitously into Toronto's built environment generated pushback (Austin & Lie, 2021). Yet such examples are rare, compared to the pace and proliferation of cross-sectoral data infrastructures to enable twin transitions with centralised policy support. CSM must balance the need to measure if low-carbon transitions have equitable effects with the need for widespread adoption in context-specific ways. This challenge of *institutionalisation* without loss of meaning has gained significance in the rapidly digitalising and increasingly digitalised Anthropocene, or what Travis (2018, p. 172) terms the digital Anthropocene, that is, a 'confluence of the digital revolution, the dilemma of climate change, and sociopolitical agency and violence'.

Digitalisation refers to applications of digital data conversion to wider organisational and socioeconomic processes (Bukht & Heeks, 2017). For institutionalisation across numerous contexts to capture diverse equity issues in socio-technical low-carbon transitions, CSM must be applicable to energy systems across degrees of digitalisation. The needs of a *highly digitalised energy system* may include automation across sectors (e.g., smart charging of transport and smart home devices that optimise time-of-use tariffs to minimise bills for users and maximise grid flexibility for utilities). By contrast, a *rapidly digitalising energy system* may prioritise grid stability and reliable tariffs (e.g., by upgrading and expanding electric grids to enable two-way power flow at high volumes and accommodate more fluctuation in power generated by renewable sources). CSM must be sensitive to these situated needs and reflect contextualised priorities of decisionmakers.

Thus, to enable transformative change in the digital Anthropocene, metrics must legitimate new institutional forms of governance premised on enacting attainable utopias (Stoddard et al., 2021). This entails identifying and enabling virtuous synergies at the confluence of digitalisation, decarbonisation and rapidly evolving data infrastructures with their possibilities and perils for equitable outcomes. In the tradition of prefigurative politics (Jeffrey & Dyson, 2021), this article approaches metrics as opportunities for institutional changes that embody better energy systems of the future, as accountable to equitable, low-carbon outcomes. It surveys three fields of scholarship and identifies pertinent insights from each to inform cross-sectoral metrical development in aid of accountable twin transitions. A schematic case study operationalises these concepts and delineates how to apply them as an analytical framework. This serves as a preliminary basis for a theory of transformative metrics.

## 2 | CROSS-SECTORAL METRICS AND ACCOUNTABLE DIGITALISATION TO LOW-CARBON ENERGY SYSTEMS

### 2.1 | Calculative logics

The first field of study this analysis draws on is ***calculative logics***, the existing theorisation of metrics; an advanced field of enquiry in science and technology studies. Calculative logics concern the basis for why things are measured in a particular way, like energy consumption as electric units in household bills, and transport in terms of distance travelled per person per mode. Energy historians have traced this complex history back to influences that commodified energy consumption in society (Daggett, 2019). The historically siloed nature of energy sector infrastructures has been reflected in metrical development (Voelker et al., 2019), such that for example, electricity usage has been measured in kilowatt hour (kWh) units, with user tariffs differentiated by total quantum of consumption, that is, charging less per unit for a basic quantum and more per unit thereafter as an equity mechanism. Yet as digitalised infrastructures integrate sectors like electricity and transport, tariffs acquire temporal dimensions with novel equity impacts, which for example, burden energy inflexible households with high costs at dynamic tariff peaks (Fjellså et al., 2021; Powells & Fell, 2019), while elite electric car owners smart-charge to access low tariffs (Chen et al., 2020).

Scholars of metrics conceptualise such transitions in terms of changes in underlying calculative logics. First, the calculative logic relies on what one is able to measure, which changes as infrastructures evolve (Heaton & Parlikad, 2019), as with rapidly diffusing smart electric metres which capture *time-of-use* at frequent intervals and can enable automation of energy demand (Sovacool, Hook, et al., 2021). Then, differentiation in terms of aspects such as low-carbon emission versus fossil fuel transport, public versus private transport, can nuance calculative logics to direct attention to socio-ecological effects (Azar et al., 1996; Mihyeon Jeon & Amekudzi, 2005). A core insight is that calculative logics are politically conditioned, and the nature of political modulation changes over time with societal trends (Moss, 2020). Calculative logics are co-shaped with data infrastructures (Lippert, 2015). Together, they determine what can be and is measured, to generate knowledge and sociotechnical imaginaries (Rommetveit & Wynne, 2017). Whether this knowledge is oriented towards socially equitable outcomes is contingent upon (i) how standardised measurements (metrics) are configured; (ii) whether this configuration is shaped by public engagement, democratic representation or other forms of decision-making; and (iii) the nature of the priorities these particular mechanisms promote. Yet these drivers of metrical configuration, these calculative logics, are obscure in day-to-day life, where people encounter infrastructures through everyday practices that are influenced by a general trust in simplified quantification (Porter, 1995).

An understanding of calculative logics is highly relevant to cross-sectoral metrical development, since ambitious emission reduction targets are being set worldwide, and must be measured in ways that cut across sectors and require new sorts of data (Nerini et al., 2018). What makes metrics *transformative* is the alignment of the calculative logics that undergird them with change agendas grounded in accountable governance to achieve transition targets; work in this regard is emergent (Walenta, 2020). For instance, Sareen (2020) shows how rapid renewable energy rollout and ambitious targets require new calculative logics for cognate sectors such as energy generation and electricity distribution, and Sareen et al. (2020) argue that combining established and innovative metrics can help monitor and address social equity, based on three comparative case studies of energy poverty metrics. Despite early attention (Hughes, 1986), research on ever-more-integrated energy sectors and implications for metrics to enable systemic monitoring and learning for transformative outcomes remains spartan. Expanding on recent advances is timely and necessary to do in a way that capitalises on well-established insights on calculative logics.

Following Sareen et al. (2020), I identify three insights as key to unpack emerging CSM in digitalising energy systems.

*The first* pertains to the importance of *historical trajectories* due to path dependency in not only metrics but in the decisionmakers who govern sectors and implement new infrastructures and metrics (Fouquet, 2016). Thus, an understanding of calculative logics must focus on material and relational ways in which incumbent, sectorally siloed modes of metricising energy infrastructure propagate and can be challenged (Stirling, 2019).

*Second*, metrics face inevitable tension between *coverage and granularity* (Bouzarovski & Thomson, 2018). A key implication is that as metrics scale up, the calculative logics at work change, and concerns of equity that are somewhat context-specific wash out at higher scales or in more generic metrics (Tong et al., 2021). This implies a need to attend to how changing calculative logics capture social equity effects.

*Third*, new forms of representation face the challenge of *policy uptake* through policy mixes that overcome path dependency (Kotilainen et al., 2019). Thus, developing CSM that can be mainstreamed requires experimentation balanced with possibilities to insert and scale these metrics across changing, coupling sectors (Kivimaa & Rogge, 2022), to become institutionalised for equitable low-carbon transitions.

## 2.2 | Institutionalisation

The second field of study that informs this analysis of transformative metrics concerns ***institutionalisation***, drawing on theories of institutional change. Accountable governance oriented at equitable low-carbon transitions inevitably requires deep changes in institutions that today govern a fossil fuel dominated world with entrenched inequities linked to energy systems, already being reproduced in energy transitions (Brock et al., 2021). At stake are battles over culture, in which institutions legitimate their power for continued authority over resources where people's interest is rarely democratically secured (Scoones et al., 2018). An agenda for commoning systems as they transition has come to the fore in research on mobility (Adey et al., 2021) and numerous sectors from urban land use to energy (Amin & Howell, 2016), at odds with their historically siloed and centrally controlled tendencies and well aligned with enabling equity. How to embed and embody such an inherently democratising approach in the key decision-making repertoires of institutions (Wyborn et al., 2019) remains a puzzle for research.

Research on transition pathways offers insights. On the one hand, it explains destabilisation of systems like currently siloed sectors (and their associated metrics) in transitioning energy systems (Turnheim & Geels, 2013) and their emphatic displacement (Sareen et al., 2022); on the other hand, scholars have typologised transition pathways based on the nature of transition (Turnheim et al., 2015). Notably, Geels et al. (2016) offer a typology of four transition pathways in any sociotechnical domain: the first where new technologies substitute the old, the second where political economic factors create pressure to transform the domain, the third where emerging and existing technologies interact to structurally reconfigure the domain, and the fourth where the existing ontology of the domain collapses without adequate replacement. Such approaches rightly regard domains (such as energy systems) and their ontologies (here energy infrastructures) as dynamic, with the orientation of transition at stake. Yet, a focus on these sociotechnical changes is most useful in ex-post analyses, whereas studying change in parallel with unfolding concerns—for example digitalisation—requires other objects for empirical examination (Haarstad & Wanvik, 2017; Loloum et al., 2021). Metrics present a window onto praxis that can enable *relational analyses* of infrastructural and institutional co-evolution (Seo & Creed, 2002). Hence a focus on CSM—barely used in transition studies so far—can yield insights on transition pathways.

A related approach is to analyse the extent of institutionalisation, where institutional change ranges from ephemeral to durable (Grandin & Sareen, 2020; Jalas et al., 2016). This implies that not all institutional change endures, and that understanding what metrics are being institutionalised is only possible by unpacking particular modes of institutionalisation, in relation to digitalising infrastructures. Whereas institutions represent the structure to steer complex energy systems using politics and policies, the orientation of governance is determined by the embodied perceptions and decisions of the actors responsible to authorise and implement change that impacts wider stakeholders, and by the means through which they are held to account by those affected by their decisions (Burke & Stephens, 2017). Bottom-up accountability is rare in energy systems, which have historically been large-scale and steered top-down (Rinkinen et al., 2019). Hence, the institutionalisation of CSM presents an opportunity to change the very ontology and orientation of energy systems to become more public-facing. This requires different, more user-centric measurements of impact (Broto et al., 2017), as I will discuss schematically in section 3. As systems become more digitalised, metrical governance must become more responsive to increasing spatial–temporal complexity in demand-side issues (Blue et al., 2020; Walker, 2021). A central challenge is to investigate and specify what such responsiveness entails, and what metrics can be instrumental in achieving it in what ways.

I identify bridging two insights as necessary to understand the institutionalisation of CSM in the twin transition.

*The first* concerns *feasible pathways for institutionalisation* of CSM, where transition studies offers a rich understanding of transition pathways that has not yet been advanced in specific relation to transition metrics. Scholarship recognises CSM as a highly innovative form of metrics (Castor et al., 2020; Nerini et al., 2018), hence the question of what pathways for institutionalisation are feasible represents an exciting conceptual challenge with real-world relevance. Theorising institutionalisation in relation to metrics requires combining an established understanding of dynamic transition pathways (e.g., Geels et al., 2016) with an appreciation of the value of relational analyses of shifting institutional authority over data infrastructures as energy systems digitalise.

*Second*, a more meta-level concern is to abstract out *principles for how to institutionalise CSM*. This builds on long-standing interest among theorists of institutionalisation as to what determines change, its pace and embedment within or displacement of organisational practices (e.g., Blue, 2019; Dambrin et al., 2007). The nature of determinants of change—what sort of CSM can be adopted by particular institutions and in what ways—potentially offers valuable insights into the nature of specific societies and their energy systems. It can provide an evidence-based way of ascertaining whether energy systems are digitalising in alignment with public interest, enhancing equity, or are driven primarily by top-down interests of incumbents or other influential minorities who extend self-serving inequitable relations of energy ownership, control and usage.

## 2.3 | Degrees of digitalisation

The third and final field of study that this analysis draws on pertains to ***degrees of digitalisation*:** Emergent literature on data justice and just transitions can be combined to understand the digital Anthropocene in terms of metrics, in a manner possible to conceptually square with analyses of accountability relations. This conceptual focus is closely linked to what Zuboff (2019) famously articulated as the rise of surveillance capitalism, which captures value from digitalisation and concentrates it in a few hands to control data flows, their monetisation and decision-making, based on intimate insight into and influence over human behaviour. Three questions guide the analysis by Zuboff (2019), concerning knowledge (who knows), authority (who decides) and power (who decides who decides). The last one is undergirded by an understanding of governmentality as *the conduct of conduct* (Foucault et al., 1991). Data infrastructures are assembled by strategic actors in specific ways that advance and subdue key interests as digitalising energy systems undergo low-carbon transitions; this has resonance with the digital Anthropocene beyond energy. Indeed, Jørgensen et al. (2013) write about the changing political ecology of human-nature relations with not only technological evolution, but the way such evolving infrastructures impact knowledge and expertise. Twin transitions, then, have political effects; these are deeply entangled with the digital Anthropocene.

Who governs data flows, how they are conditioned by data infrastructures, who is privileged and who is excluded by them is at the core of data politics and justice (Dencik et al., 2019). Scholars have proposed means to study and advance data justice to secure the interests of marginalised groups subjected to rapid digitalisation and datafication (Heeks & Shekhar, 2019), elements that are necessary for a just transition (Heffron & McCauley, 2018; Newell & Mulvaney, 2013). These emerging insights must be tested across sectors to unpack their real-world impact. They are yet to be thoroughly applied to digitalising energy systems, even as data infrastructures become embedded in and modulate energy end-use in contexts at the forefront of digitalisation. CSM can help inform assessments of data justice in a manner systematically integrated in sociotechnical systems.

The term just transition has recently gained traction and refers to sociotechnical system changes, specifically in low-carbon directions to advance climate mitigation, while simultaneously increasing social equity and inclusion. Achieving a just transition requires power to enact change, legitimacy to authorise a normative orientation to low-carbon systems, and insight into 'before' and 'after' states to assess the nature of change—does it advance low-carbon sociotechnical systems in equitable ways? Energy policy is at the heart of achieving just transitions, as it sets the terms to direct major infrastructural changes. Yet as energy infrastructure is digitalised, the institutions that set energy policy themselves change. An underlying assumption in decision-making is that empowering users with data to stake claims can enable just energy systems in the future; but recent studies problematise this assumption by probing the capacities and contexts of the impacted users (Fjellså et al., 2021; Sovacool et al., 2020; Sovacool, Turnheim, et al., 2021). Cross-sectoral studies across contexts with diverse degrees of digitalisation are needed to understand its impact on just transitions.

Recent headway has been made on the ethics of digitalisation and the ever-increasing rendering of key parts of societal infrastructure (here energy infrastructure) into streams of quantified data that constitute the digital Anthropocene. Amoore (2020) has proposed *cloud ethics* for algorithmic accountability, with the aim of identifying ways to highlight the sociotechnical contexts which data streams operate on and the impacts of reductive analyses on decision-making. Similarly but with an explicit energy system focus, Hillerbrand et al. (2021) problematise digitalisation for its justice impact on users of electricity and transport, highlighting complex equity-related choices.

Digitalisation thus plays a salient role in defining the equity effects of energy systems as these are articulated in infrastructural development during low-carbon transitions (Andersen et al., 2021; Sareen, 2021). This recognised intersection has led to emergent work while empirics remain preliminary: as yet, there is no solid empirical basis for appreciation of how equity effects vary by degree of digitalisation, and correspondingly, what choices decision-makers need to be acutely conscious of as they steer changes in variously digitalised and digitalising contexts, in the digital Anthropocene. At stake is the intended development of digitalised energy systems that serve public interests, referred to as commoning (Adey et al., 2021; Nikolaeva et al., 2019), versus the production of new forms of enclosure, elite capture and surveillance across societally ubiquitous systems (Bridge, 2011; Bridge & Gailing, 2020; Zuboff, 2019). While these tensions of digitalisation are hardly new (see e.g., Graham, 1998), their effects at this critical juncture in digitalising energy systems, and variation across space (cf. Bridge, 2018), constitute emergent and urgent elements of an expanding research frontier.

The particular task at hand for scholars in relation to this literature is to build on the following two aspects.

*First*, theorisation of the *intersection of digitalising energy infrastructures and metrics* that (can) propagate in emergent data infrastructures of low-carbon energy systems. This is a rapidly evolving set of infrastructures, both multispatial in reach and place-based in impact, and metrics can be hard to track and specify reliably.

*Second*, an explicit analytical *link between data justice and just transitions*, which adds a normative layer to the work of metricising digitalising energy infrastructures across increasingly integrated sectors. This is a key task underway in order to analyse the normative implications of decision-making within contexts at various degrees of digitalisation, from basic, sporadic energy access to high-powered, digitalised life.

## 3 | OPERATIONALISING AN ANALYTICAL FRAMEWORK AND APPLICATION TO A CASE STUDY

Having assembled a tripartite conceptual approach to CSM as accountability tools in twin transitioning systems towards a digital Anthropocene, I operationalise an analytical framework and delineate its application to a case study. This is done schematically, to illustrate its scope and value. The case study is chosen based on its high ambitions on digitalisation and decarbonisation, and my contextual familiarity. Given space constraints and nascent changes, a referenced analysis is not provided, nor are precise details of importance; the main aim here is to demonstrate how the three conceptual strands are mobilised.

Consider Stavanger, a mid-sized city of 230,000 inhabitants in Norway, and one of 112 Mission Cities selected by the European Commission for their ambitions to be climate neutral by 2030.

Stavanger has ambitions to lower its urban transport emissions drastically over this period, has smart grid infrastructure for electricity distribution down to smart electric metres in each building (97% of households in Norway), and already has an electric grid run almost entirely on renewable energy sources (primarily hydropower). It is thus seemingly well poised to make a twin transition of digitalisation and decarbonisation in and across these sectors: urban transitions, electricity distribution and electricity generation. Let us examine what this means in terms of calculative logics, institutionalisation and degrees of digitalisation.

## 3.1 | Calculative logics

Historical trajectories show these sectors have been governed in siloes. Norway's electric car rollout, celebrated as a frontrunner, reached over 80% market share in new car sales by 2022. This makes smart car charging increasingly common among affluent households. Following distribution grid digitalisation to household level, a national online platform ElHub was launched in 2019 to make real-time data on building-level electricity demand available to registered vendors. Digitalisation is unleashing innovation in dynamic tariffs with many options for consumers. With increasing electric market integration through grid interconnection with Europe, electricity generation has faced novel challenges with high gas prices in Europe during the war in Ukraine driving up household electricity tariffs in Stavanger despite large hydropower production in its vicinity. These developments have raised questions on tariff structures and led to conflict and changes. Thus sectoral coupling is forcing shifts away from historical practices.

Distribution grid operators have started valuing flexibility more, and now charge households more on fixed charges based on the highest three peak demand hours per month. The government is subsidising the spot price (variable) charges by 90% of the amount above 0.70 kroner per kWh, averaged out over a month based on the aggregated spot price. Households can choose dynamic tariffs or fixed tariffs, but companies have hiked the latter due to uncertainties, making them a poor choice. Households with electric cars and smart charging can programme these to charge off-peak at low tariffs, in the process helping balance grid supply and demand. Thus, electricity generation, end-use and transport sectors have become more tightly linked than before, with emerging CSM trying to balance granularity and coverage. Yet this is difficult, as household subsidies up to 5000 kWh per month have seen some households with cheaper long-term fixed tariffs receiving higher state subsidies than their electricity bills, creating a perverse incentive to consume.

Traditionally used metrics do not easily capture equity effects of this twin transition. Electricity bills have become complex, and regional electricity generation is a poor predictor of electricity price due to large grid interconnections that drive prices remotely, with steep inter-day and intra-day variation. Elite households with electric cars and smart charging can benefit from automated access to lower tariffs, whereas families with children and inflexible electricity needs (e.g., to cook dinner, do laundry, use the computer and take a warm shower) may have large bills by landing in a higher fixed charge bracket and getting less benefit from the subsidy. Thus, there is a need to enable policy uptake of CSM that capture equity effects of how dynamic tariffs, transport energy demand and electricity market regulations impact diverse user groups, in order to identify how subsidies can be more justly targeted and whether they are having intended effects.

## 3.2 | Institutionalisation

Consider how policy mixes can enable policy uptake of CSM. To capture effects across different sectors such as transport and electricity distribution, CSM would require coordination between these sectors. Yet, the institutions that govern each sector operate separately. Historically, their cooperation is limited to wholesale electricity demand for some larger electrified transport systems like the railways, or Norway's only urban subway system in Oslo. With electric cars, buses and bicycles proliferating in Stavanger, placing charging capacity at many nodes throughout the city and beyond (for longer trips) and devising fair tariffs becomes important. Feasible pathways for institutionalisation of CSM then become those that can be willingly accommodated by the institutions that govern these sectors in cooperation, including the need to share real-time data and develop cross-sectoral targets. For example, vehicle charging should ideally be diverted to off-peak hours, to avoid burdening households with inflexible essential electricity needs (for cooking, space heating, domestic utilities and lighting, all of which are primarily electric in Norway) with high tariffs. Yet, Stavanger's climate action plan 2018–2030 makes no mention of CSM, remaining limited to sector-wise targets, such as percentage reductions in transport modal usage. This overlooks the importance of real-time coordination that drives value in the digital Anthropocene.

At a higher level of abstraction, institutionalisation of CSM goes beyond simply identifying the right ones, which itself is a complex task. It is necessary to create recognition among decisionmakers of the need for such CSM, and if they require additional investment in data infrastructures, then to inform wider publics to create legitimacy to realise such measures. It is likely that the most optimal set of CSM will not be the ones possible to measure most efficiently across sectors and their institutional authorities. Hence, finding a balance between efficiency and the political willingness for cross-sectoral coordination is key here.

## 3.3 | Degrees of digitalisation

A consideration to guide choice of CSM is their role in enabling data justice. What are important metrics for households to secure just outcomes in digitalised energy infrastructure practices? Stavanger presents a valuable context to understand this, as its frontrunner status in digitalisation and ambitions of low-carbon emissions brings issues at this intersection to the fore well before they become relevant for policy in many places. The advent of ElHub makes real-time household electricity demand data available to registered vendors, which albeit anonymised, can be used to gain valuable insights on trends. In what ways this value is extracted and by whom remains beyond the knowledge of most users and is driven by industry-state deliberation of a primarily technical nature with wider societal implications. A focus on CSM would draw attention to what data flows are being captured and for what purposes, to secure public benefits such as a basic minimum share of affordable electricity tariffs across cross-sectoral electricity usage per household.

This brings us to the link between data justice and just transitions, which entails ensuring that CSM are at the service of informing a digital Anthropocene oriented towards a more just, low-carbon energy system. To take a single prominent example from many possible ones in Stavanger, the explosion of highly subsidised and incentivised electric cars comes at a cost of expanding local electricity demand primarily by elite households. While positive in terms of displacing fossil fuel use in urban transport, it can be critiqued for diverting limited resources away from electrification of public transport, and prioritisation of less energy intensive forms of transport than personal automobiles. A CSM that captured distribution of benefits from state subsidies and incentives to energy intensive solutions per household versus more collective ones would highlight the regressive effects of prioritising electric cars over more modest, collective electricity uses. CSM can thus be constructed in ways that reflect decision-making on desired degrees of digitalisation. These need not extend the digital Anthropocene to hubristic extremes, and can prioritise the creation of digitalised and electrified commons that serve wider public needs over those of elite households.

## 4 | CROSS-SECTORAL METRICS AS ACCOUNTABILITY TOOLS TO DIAGNOSE AND ORIENT TWIN TRANSITIONS

In light of the above, I argue that attending to calculative logics, institutionalisation dynamics, and degrees of digitalisation to enable CSM can advance our ability to diagnose and orient twin transitions. CSM thus become accountability tools for the digital Anthropocene, informing and equipping those who wish to unpack its potential and safeguard against its attendant perils. It is possible that CSM in themselves are not transformative; in fact, most will not be. Only some CSM match the calculative logics of low-carbon transitions, only some of these can be institutionalised across sectors with multiple institutional authorities, and only some of these serve to inform practitioners in line with data justice ideals for a just transition. Yet by virtue of this tripartite analytical process with the conceptual undergirding provided above, CSM selected as heuristically articulated for the Stavanger case study necessarily constitute *transformative metrics*.

I have argued for the need to metricise accountability in twin transitions, which present an opportunity to embed CSM as accountability tools into emerging data infrastructures, institutionalising them to render them into transformative metrics. Given that digitalisation is already rapidly underway in frontrunner contexts like Stavanger, the 2020s are a fleeting window of opportunity where strategic self-interest threatens to dictate proceedings and push sociotechnically sub-optimal metrics into place. This is evident in the lack of existing CSM embedded in municipal policies and targets, which remain sectorally siloed despite evident sectoral coupling through digitalisation. Proactive interventions that identify and institute CSM in service of equity across sectors are required, and academic initiative can help. At stake here is the desirable development of a digital Anthropocene with data infrastructures that provide us accountability tools to inform decisionmaking for just transitions, versus data infrastructures that perpetuate an unjust status quo of energy systems steered by narrow self-interest of elite incumbent actors, with digitally coupled sectors. The latter may well achieve a twin transition of digitalised low-carbon energy systems, yet would leave the political economy of the Anthropocene untouched, and potentially more entrenched through digitalisation.

Consequently, an urgent task towards accountable twin transitions is to combine understanding of metrology, and of existing and evolving metrics, with a focus on the recursive interactions between energy metrics and transitioning energy systems over time (from $T_1$ to $T_2$), by drawing on Sareen (2020), Figure 1). This analytical framework approaches institutionalisation as a relational phenomenon where actors contest existing institutional authority by utilising four practices of legitimation: discursive, bureaucratic, technocratic and financial. This legitimation reconfigures accountability relations, giving rise to an adjusted assemblage of actors and relations, which in turn are captured by new energy metrics and energy systems (also see Sareen, 2021; Sareen & Wolf, 2021). Such a relational understanding of the interaction between metrics and transitioning energy systems can be used to investigate how CSM can be institutionalised at the service of equitable low-carbon transitions, suitably refined by engaging with key insights from scholarship on transition pathways.

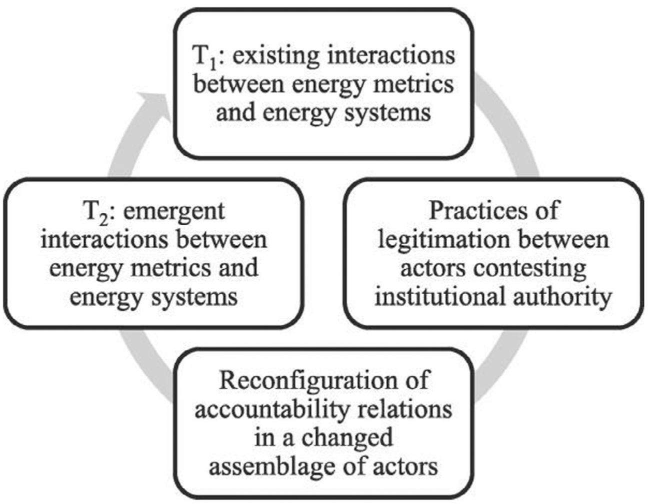


**FIGURE 1** Conceptualising institutionalisation of new metrics in twin transitions. *Source*: Sareen (2020, p. 32).

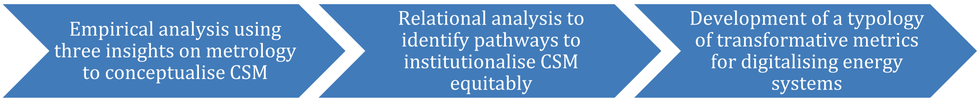


**FIGURE 2** Towards a theory of transformative cross-sectoral metrics (CSM) for accountable twin transitions.

Sets of pathways to institutionalise CSM towards equitable low-carbon transitions, once identified and developed, can be analysed across energy systems with a wide range of degrees of digitalisation, rather than a single case study as with the schematic treatment of Stavanger above. At every degree of digitalisation, decisionmakers face choices about how to encode quantification of data into new aspects of energy systems, with far-reaching implications for how equity issues can be understood and measured. This lays the groundwork for whether and how publics can hold power-holders to account (Fox, 2022). Framing the effects and dynamics of CSM with respect to digitalising energy infrastructure can inform the development of a typology of transformative metrics, as a tool to orientate accountable twin transitions to equitable, low-carbon energy systems in the digital Anthropocene.

Figure 2 builds on the analytical framework delineated above to suggest the way towards a theory of transformative metrics, which would be directly applicable to digitalising energy systems. Empirical and conceptual analysis along indicated lines can inform and refine the visualised heuristic. This is a task for future programmatic research on accountability, in order for scholarship to achieve an adequate response to the realities of the digital Anthropocene and its changing energy systems and data infrastructures, and indeed to inform and orient power-holders as they put novel metrics into play. The nature of the work entailed requires collaboration across disciplinary boundaries, and synergistic competencies such as ethnographic and quantitative analysis, as well as an understanding of diverse complex sociotechnical systems. While by no means an easy task, the clarity of its necessity is a humbling reminder of the challenging nature of ensuring accountability in the rapidly digitalising Anthropocene, when the conditions that have led us here are in many ways premised on a lack of accountability. Indeed, there is no dearth of risk of accountability traps and even strategic gaps by self-serving actors who abuse metrics (Arnold, 2022; Park & Kramarz, 2019). Hence, to conclude on a sobering note, this call for devising, critically assessing and institutionalising CSM is indeed a call for transformative metrics, that can harness metrical power to enact ambitious programmes of social change embedded in twin transitions. The delineation of an analytical approach that can operationalise and apply conceptual underpinnings to contexts of an emergent digital Anthropocene is a step towards a needed theory of transformative metrics.

## 5 | ACCOUNTABILITY TOOLS FOR THE DIGITAL ANTHROPOCENE

In closing, I move from the conceptual contribution to the practical implication of the argument presented. State and non-state actors have roles to play in promoting the cross-sectoral accountability mechanisms outlined above with a focus on transformative metrics. Metrics do not achieve real-world change in themselves, but rather present a set of standards that serve to orient and course-correct practitioners by making them robustly aligned with the ambitions they have articulated and agreed to. Lidskog and Sandrin (2023) term this sort of means for adaptive alignment in the exercise of accountability relations 'justificatory social interaction'. Their observation is crucial in its acknowledgement of accountability as not a sufficient condition to transform society to sustainability, but as an important component of a broader set of mechanisms that structure relational mobilisation. My argument has focused on the constitution of transformative metrics as some of these very mechanisms, that can become instrumental in bringing accountability to bear on societal transformations to sustainability.

From a practical perspective, centring CSM to guide action towards equitable impact in moving towards digitally connected, low-carbon systems (the work of embracing transformative metrics) requires decentring some other forms in which 'justificatory social interaction' plays out. There is a lot of noise around low-carbon transitions, and the loudest voices are typically those with the most privilege, which often correlates to incumbent roles and biases in favour of the status quo to protect that privilege. For state and non-state actors alike, this creates confusion and challenges in articulating and pursuing a course of action that achieves the espoused goal of reducing carbon emissions in socially equitable ways. Centring transformative metrics can ease this confusion for state actors, presenting the advantage of being able to point to rigorous orienting standards in relation to which they can showcase progress or justify changes in transition strategies. Transformative metrics can thus give politicians and policymakers more scope to follow the courage of their convictions for medium- and long-term changes in line with their transition targets, as they can showcase the orientation of salutary effects by pointing to these metrics. For non-state actors, transformative metrics can serve to limit the role of rhetoric, hand-waving and greenwashing that stymie public debate, by presenting clear standards on which these debates can centre. Even for the most privileged incumbent, having a robust yardstick that shows their championed strategy taking society off course is an embarrassment, whereas even the most marginalised of actors can gain traction for their critique by pointing to deviations from the standards that performance is measured against.

Transformative metrics are no cure-all. They will not make the work of implementing accountability any less a task that is perpetually in progress in a world rife with unequal power relations. Yet, they can make task definition clearer and easier to align with action during the rapid digitalisation and decarbonisation of ubiquitous energy infrastructure. They thus constitute vital accountability mechanisms for just twin transitions in the digital Anthropocene.

## ACKNOWLEDGMENTS

The author acknowledges funding from the Research Council of Norway grant 321421 (ROLES) and grant 314022 (ASSET) that made this contribution possible, and wishes to express gratitude to the special issue editors for this thematic collection and curating a constructive external peer review process.

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**How to cite this article:** Sareen, S. (2023). Cross-sectoral metrics as accountability tools for twin transitioning energy systems. *Environmental Policy and Governance*, 1–11. https://doi.org/10.1002/eet.2079