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Governing electronics sustainability: Meta-evaluation of explanatory factors influencing modes of governance applied in the electronics value chain

Richard Evans [a, #, *], Walter J.V. Vermeulen [b]

[a] Utrecht University, Vening Meineszgebouw A, Princetonlaan 8a, 3584 CB, Utrecht, the Netherlands
[b] Copernicus Institute of Sustainable Development, Utrecht University, Vening Meineszgebouw A, Princetonlaan 8a, Room 7.34, 3584 CB, Utrecht, the Netherlands

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ABSTRACT

Electronics are produced, consumed and disposed of through a highly complex, globalised value chain, creating numerous challenges in the governance of sustainable electronics. To understand how sustainability is governed throughout the electronics value chain, this paper uses current literature to analyse the structure (e.g. actors) and composition (e.g. policy instruments) within electronics governance. These articles are then used to derive explanatory factors for the level of governance effectiveness in terms of sustainability outcomes across the electronics lifecycle. Conclusions show that state and corporate forms of governance have the most impact on sustainability. However, interactive mechanisms for sustainability governance which incorporate governments, companies, and civil society organisations can build trust and cooperation between actors. Moreover, incorporating various actors in a complimentary manner can reinforce government and corporate approaches, as a result, interactive governance may yield long-term sustainability results in the electronics industry.

Contents

* Corresponding author.
E-mail addresses: rco.evans@gmail.com (R. Evans), W.J.V.Vermeulen@uu.nl (W.J.V. Vermeulen).
[#] Present Address: 10 McAdam Close, Hambrook, Chichester, West Sussex, England. PO18 8FG.

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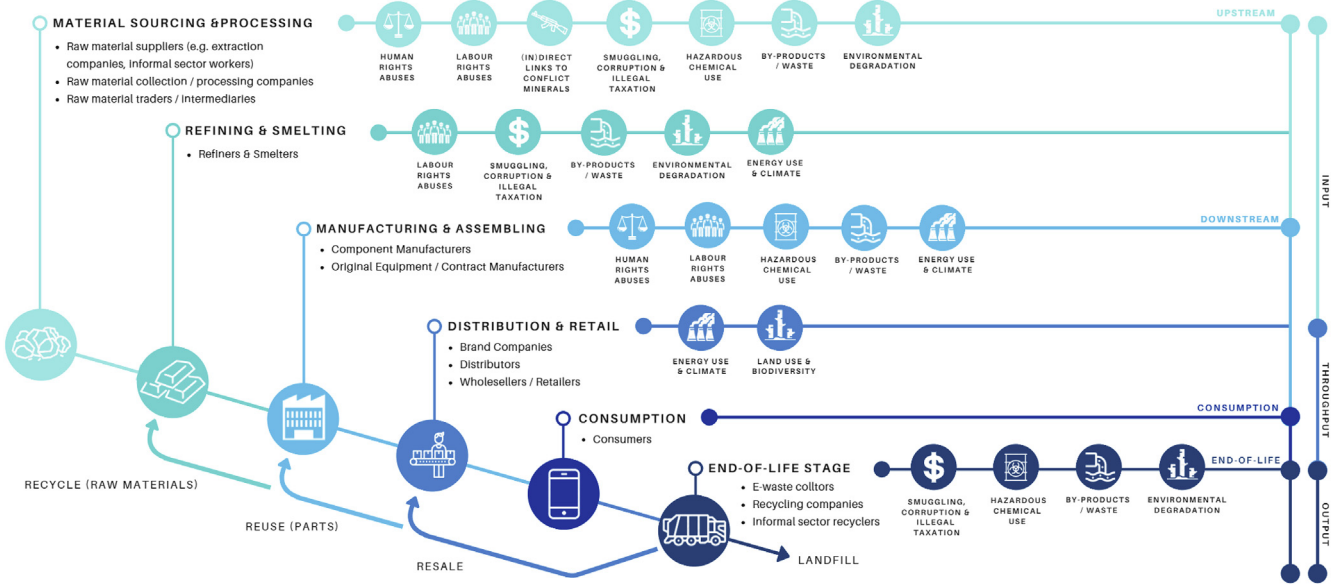

Fig. 1. Infographic showing the main actors and sustainability risks relating to the electronics lifecycle and their position within various stages of the electronics global value chain.

1. Sustainability risks in electronics value chains

Growth in the electronics industry since the 1980s is archetypical of a globalised and technology-centric society. Yet, electronics are linked to a range of negative sustainability impacts or 'risks' throughout their lifecycle, as shown in Fig. 1 (Overeem, 2009; Evermann, 2014). These risks occur globally but disproportionately affect developing countries, particularly where weak public institutions and limited state authority allow risks to emerge and establish (Hofmann et al., 2015; Jameson et al., 2016).

Sustainability risks can be attributed to the challenges of governing sustainability in global supply chains, which fragment and disconnect the various stages of the electronics lifecycle across international borders (Evermann, 2014; Hofmann et al., 2015). In this context, the term 'supply chain' can be better conceived using the global value chain (GVC) framework, which conceptualises the global nexus of connected actors, processes and exchanges across the electronics lifecycle[1] (see Gereffi *et al.*, 2005). Within this system, sustainability governance is also undermined by the characteristics of international trade, whereby exchanges between suppliers and buyers are dynamic and kept confidential (Hofmann et al., 2015; Amnesty International, 2016; Jameson et al., 2016; Young, 2018). Consequently, information regarding the conditions in which electronics are produced and disposed of is often obscured by limited transparency between actors in the GVC, creating 'governance gaps' for sustainability (Young et al., 2010). Thus, allowing illegally produced or unsustainable minerals, components and recycled material to enter the global market, while also resulting in the non-allocation of accountability among companies that contribute to (directly or indirectly) unsustainable practices (Prenkert, 2014; Hofmann et al., 2015; Martin-Ortega et al., 2015; Jameson et al., 2016).

In this setting, sustainability science aims to elucidate the dynamic relationships between, as well as within, social and ecological systems. The purpose of which is to critically evaluate the impacts of human-induced changes on the environment and socio-economic development, with a view to managing impacts through systems of governance (de Vries, 2013). Here, governance can be understood as the arrangement of, and interactions between, various actors, institutions and policy instruments (Driessen et al., 2012). Moreover, examining governance can serve as a tool for diagnostic and prescriptive inquiry and, as is the purpose of this article, it is possible to analyse comparative forms of sustainability governance and the variables that contribute to successful (i.e. effective) solutions to sustainability dilemmas. However, the arena in which governance takes place is dynamic and complex; governance modes can co-exist and interact in various ways and at various scales (Abbott and Snidal, 2009). Therefore, to evaluate the effectiveness of environmental governance, Driessen et al. (2012) recommend systematic analysis of its structure (i.e. actors) and composition (i.e. policy instruments[2]).

In evaluating current literature, this article identifies how sustainability governance in the global electronics value chain is characterised by a diverse actor base and evolving relationships of power and dependency between state, market and civil society actors (Raj-Reichert, 2011). Sustainability in the electronics industry is addressed from various angles in contemporary literature, including production and consumption (e.g. Overeem, 2009; Raj-Reichert, 2012; Martin-Ortega, 2018), corporate management (e.g. Chien and Shih, 2007; Cook and Jardim, 2017; Hsu and Chang, 2017), and waste management (e.g. Osibanjo and Nnorom, 2007; Wath et al., 2010; Daum et al., 2017). Yet, this literature tends to focus on specific actors (e.g. market actors), specific policy instruments (e.g. state or industry policy), or on specific sustainability concerns (e.g. labour rights). Thus, making it difficult to determine the overall effectiveness of sustainability governance across the electronics lifecycle. Therefore, this article, by conducting a meta-evaluation of sustainability governance in the literature, pieces

[1] In practice different disciplines use the terms supply chain, value chain and product lifecycle in paralell when explaining global systems related to electronics production, consumption and end-of-life processes. This article predominantly draws on the global value chain framework, although other terms are used when appropriate. This is because value chains better conseptualise the actors and relationships involved in these systems and their organisation across geographic space. Thus, supporting the analysis of electronics sustainability governance mechanisms.

[2] i.e. regulations (voluntary or legal), standards, codes of conduct etc.

together the multi-faceted landscape of governance research on the global electronics value chain. In doing so, using the literature to critically analyse the structure and composition of governing sustainability across the electronics lifecycle, with an eye to identifying factors which influence the overall level of governance effectiveness in terms of sustainability outcomes.

We will discuss our review in the preceding format: Section 2 outlines the methodological approach used, followed by an overview of trends within the theoretical literature (Section 3) and analysis of the structure and composition of sustainability governance in Sections 4 and Section 5. Finally, Section 6 discusses the overall effectiveness of governance and the implications of this for state, civil society and industry stakeholders are addressed in Section 7, before conclusions are given in Section 8.

2. Method: case selection and analysis

An online bibliographic database search was used to identify 80 relevant empirical articles, which were analysed to gather basic information from each article[3] (e.g. authors, publication year, sustainability risks, governance actors). Steps were taken to ensure articles address comparable governance concerns while being representative of academic, industry, civil society and government sources. It should be noted that sustainability is an interpretive and contested concept within and between these sources (Vermeulen, 2018). For evaluation purposes in this article, sustainability is understood using the concept of People, Planet, Prosperity (3Ps).[4] This is a commonly accepted framework for sustainable development and focuses on the elimination of poverty, meeting basic human needs, protecting the environment for present and future generations, as well as reducing inequality and improving quality of life globally (Brown and Rasmussen, 2019). Furthermore, this article concentrates on the electronics industry,[5] rather than industries impacted by similar sustainability risks (e.g. automotive, appliances, jewellery). This is because the electronics industry boasts a range of sustainability initiatives which have emerged in recent years, along with literature evaluating these.

An initial review of the literature was used to extract data and identify broad trends within the field of study, as outlined in Section 3. This is succeeded by more in-depth analysis focusing on the structure (i.e. policy actors) and composition (i.e. policy interventions) used within electronics governance across the GVC (Sections 4 and 5). Within this, descriptive and axial coding is used to identify actors and abstract policy interventions used to engage in sustainability governance. These are categorised using Driessen *et al.* (2012) typology of governance modes within environmental governance (i.e. 'Centralised', 'De-centralised', 'Public-private', 'Interactive' and 'Self-governance'), which describe the actors involved in policymaking, their interactions (i.e. institutions), as well as the product of these interactions (i.e. policy interventions). The purpose of this is to analyse the causal relations between sustainability interventions and how the outcomes of these interventions (independent variables) influence the conditions for effective sustainability governance within each stage of the GVC (dependent variable). Here, governance effectiveness is determined using the author's argumentation regarding the extent to which described interventions and governance modes achieve desired result variables, summarized in Tables 2–4.

Finally, to bring together the diverse literature a value was assigned to each article based on the extent to which the described interventions and governance mode(s) produce desired sustainability outcomes. For example, effective governance modes score 2, semi-effective modes needing improvement score 1, and those which negatively affect sustainability score −1. While simplistic, this approach was used to quantify arguments in the literature and provide a methodological approach for evaluating governance effectiveness. Totalling scores for each governance mode provided a measure of effectiveness within the respective stages of the global electronics value chain, as well as the overall impact of each mode on sustainability (shown in Table 5).

3. Sustainable electronics governance literature

Within the empirical literature, three distinct stages are identifiable across the global electronics value chain concerning sustainability risks and governance. These focus on 1) *input processes,* incorporating mineral sourcing and manufacturing; 2) *throughput processes*, concerning corporate sustainability governance among consumers and electronics brands[6]; and 3) *output processes,* focused on the post-consumption and end-of-life (EoL) stage for electronics. As shown in Fig. 1 these stages provide a framework for conceptualising the actors within the electronics value chain, their relationships across the electronics value chain, as well as links to sustainability risks. Within this, electronics brand companies are grouped into the throughput stage due to their ability to interact and control processes across the electronics value chain, making this a focal point in the value chain where value and power are centred. From this point, all upstream actors and processes are considered to be inputs, while those further downstream are categorised as outputs. The aim of this is to simplify the electronics value chain as a way to aid the evaluation of sustainability governance in the literature, which is distinctly different cross these stages.

By examining trends in the literature, governance research can be understood as an evolving field between 1999 and 2018 (see Fig. 2). Since 2009 input processes have emerged in the literature, which follows a phase dominated by articles on output processes. Meanwhile, the literature focused on sustainability governance at the corporate level remains relatively consistent. Furthermore, as shown in Fig. 3 there is a relatively even distribution of research between the three main stages of sustainability governance in the GVC, which can be used to conclude that sustainability risks are equally as poignant within each of these stages. However, this does not mean to say that all sustainability risks receive equal representation in the literature. For example, Fig. 4 shows the location of case studies used to research sustainability risks in the GVC. Highlighting, that sustainability risks tend to occur in developing countries, particularly in Asia. Yet, the research itself is disproportionately conducted by academics associated with institutions in developed economies, particularly Europe and North America. This may result in some risks receiving less attention due to a lack of 'western' understanding or data availability, particularly due to the complexity and concealed nature of risks within more remote stages of the GVC (both upstream and downstream). This perhaps

[3] See supplementary materials for recorded data.

[4] This framing of sustainability emphasises social, environmental and economic development and is incorporated into multilateral frameworks like the UN sustainable development goals (SDGs) to conceptualise the broad yet interconnected nature of sustainability risks.

[5] Here, electronics are defined as technological devices which use electrical charge in logic circuits for complex functions (e.g. TVs, mobile phones, PCs), rather than 'electrical' devices which simply use electricity (e.g. lighting, kitchen appliances, tools) (Lexico, 2019). Although, it is worth noting that electrical devises are taking on ever more complex functions as technologies become more diverse and cheaper to produce, blurring the line between 'electrical' and 'electronic'.

[6] Electronic brand companies are also commonly referred to as 'lead' or 'focal' companies in the literature.

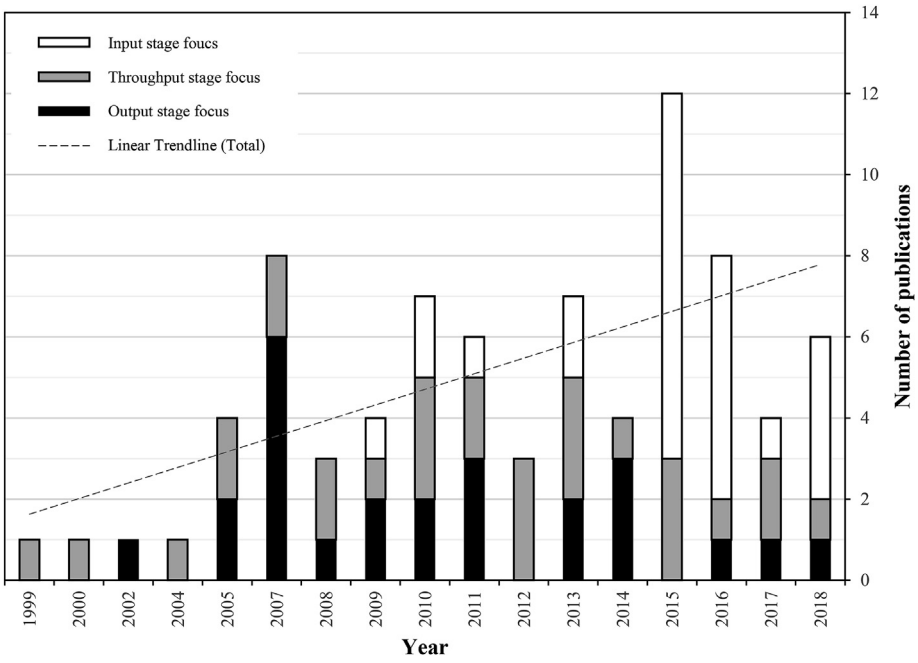

Fig. 2. Column graph showing the number of empirical articles published relating to 'Sustainable Electronics Supply Chain Governance' every year between 1999 and 2018. The trend line shows the linear annual change in articles published based on the total number of publications in the sample period. Published articles are also categorised based on which stage(s) of the electronic value chain the research focuses on (i.e. input, throughout and/or output stages).

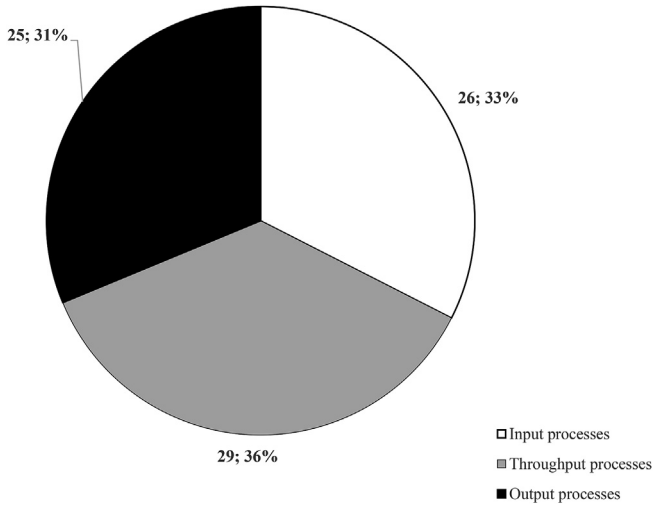

Fig. 3. Pie graph showing the proportion of the empirical articles (%) within the electronics supply chain governance literature (1999–2018) which focus on each of the electronics value chain stages (i.e. input, throughput and output stages).

also explains the slight research bias towards corporate governance approaches in the literature, as many electronics brands are headquartered in western countries.

The analysis also shows that conceptualisations of sustainability have changed within electronics governance since 1999, with literature shifting from an environmental focus to more balanced and holistic views of sustainability based on the concept of the 3Ps (see Fig. 5). Despite this, articles use varying understandings of sustainability, reflecting broader debates within sustainable development on the definition of sustainability (Vermeulen, 2018). The disputed nature of sustainability can leave it open to manipulation, for example, the inclusion of corporate profit as one of the 3P's within sustainability measures (Martin-Ortega et al., 2015). This also reflects the complex institutional settings within which sustainability governance happens, where multiple actors are involved in policy design, implementation or enforcement. As shown by Fig. 6, market, state and civil society actors all as initiators in varying governance arrangements and with differing (potentially competing) agendas, with a relative dominance of market actors.

4. Structure of electronics governance

To evaluate the complex dynamics of electronics governance further, the analysis focuses on the actors involved in electronics governance (summarized in Table 1) as well as how these actors engage and interact within governance. To do so, this article employs the 'governance triangle' approach based on Abbott and Snidal (2009) to represent the potential 'regulatory space' in terms of sustainable electronics. As shown in Fig. 7, the model is divided into zones to express how Market, State[7] and Civil Society actors interact at the policy-level. Concepts from the literature were used to map each article and differentiate these based on the GVC stage in which this takes place, as well as the 'mode of governance' used (also summarized in Fig. 8). For the purposes of value chain analysis, the use of stages such as input, throughput and output is a recognised approach, as demonstrated by Reike et al. (2017).

State governments are traditionally responsible for protecting the rights of domestic citizens and the environment via planning, implementing and enforcing state policy. This is conducted among civil servants within ***de-centralised*** public institutions, who make rational top-down decisions in the public interest. As shown in Fig. 7 (Zone 1) and Fig. 8 many authors discuss the need for state sustainability interventions, especially regarding output-side processes (e.g. Osibanjo and Nnorom, 2007; Manomaivibool, 2009; Shumon et al., 2014). Although, state responsibilities are embedded within a wider context and influenced by **supranational state**

[7] Both state and supranational state actors have been combined in Fig. 7.

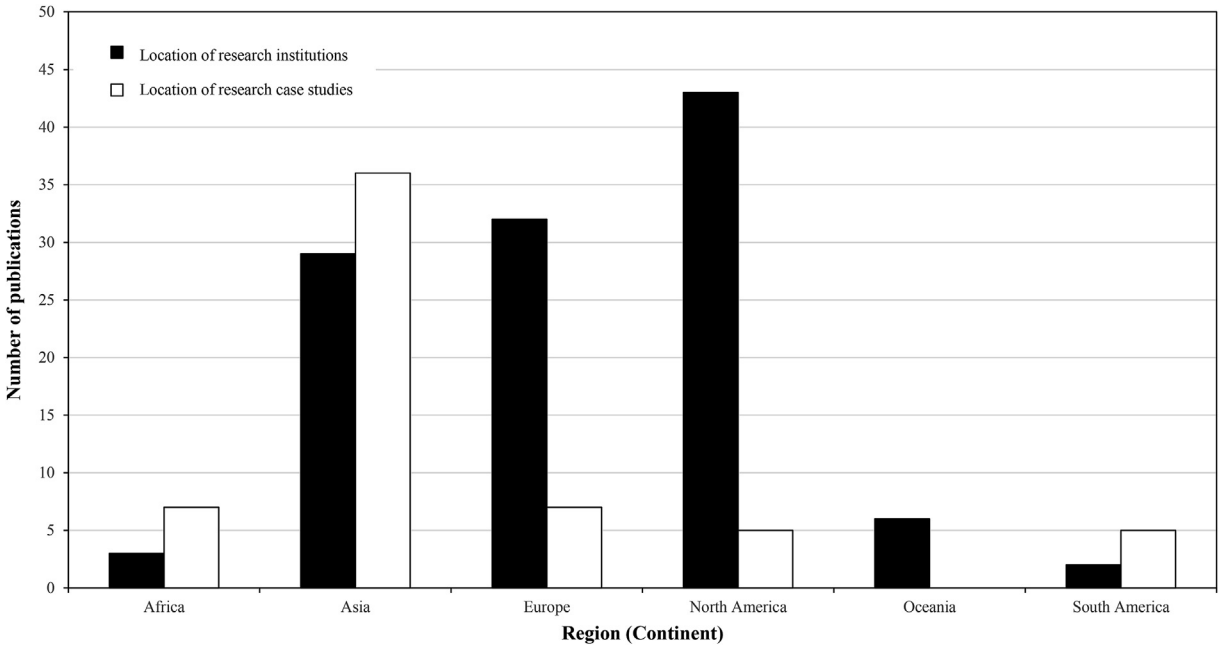

Fig. 4. Column graph comparing the location of case studies (by continent) used in the electronics governance literature to research sustainability risks (1998–2018), with the origins of the research itself based on the location research institutions affiliated with publication authors (by continent).

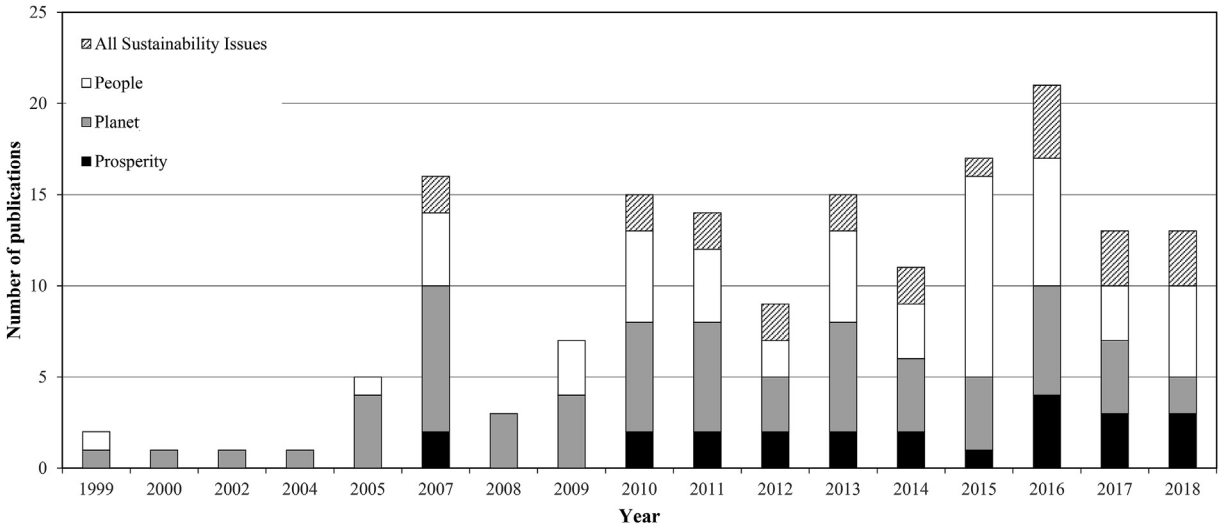

Fig. 5. Column graph showing the number of empirical articles on electronics governance literature published each year between 1999 and 2018. Articles are grouped based on which of the three dimensions of sustainability they incorporate (i.e. People, Planet or Prosperity). Empirical articles which incorporate all of these dimensions are categorised accordingly.

institutions. For example, policies defined by the EU (e.g. Restriction on Hazardous Substances [RoHS] directive and Waste electrical and electronic equipment [WEEE] directive), outline transnational sustainability criteria for electronics via a ***centralised*** approach.

Yet, it is unrealistic to expect a long-term solution to sustainability problems from state governments alone, particularly in high-risk countries where sustainability policy lacks coherence and/or effectiveness on vertical and horizontal axes[8] (Prenkert, 2014; Hofmann et al., 2015; Jameson et al., 2016; Young, 2018). In the absence of the state capacity or willingness to enforce sustainability standards in some countries, **international actors** like the United Nations (UN) and Organisation for Economic Cooperation and Development (OECD) have established universal sustainability benchmarks (United Nations, 2011; Amnesty International, 2016). These define standards for issues like human rights, safe working conditions, environmental protection across the GVC, while also assigning regulatory and enforcement responsibility to state and/or market actors (Amnesty International, 2016). Here, electronics brands are critical actors within sustainability governance, whose access to consumer markets drives value-creation and, ultimately, has the largest influence over the GVC (Young et al., 2010; Prenkert, 2014; Callaway, 2018). In recognition of the

[8] Vertical incoherence occurs when a state adopts a human rights obligation but fails to give enough regard or effort to its implementation. Horizontal incoherence occurs when states regulate one area in isolation with little regard for how that interacts with or effects regulatory efforts elsewhere (Ruggie 2009; in Prenkert, 2014).

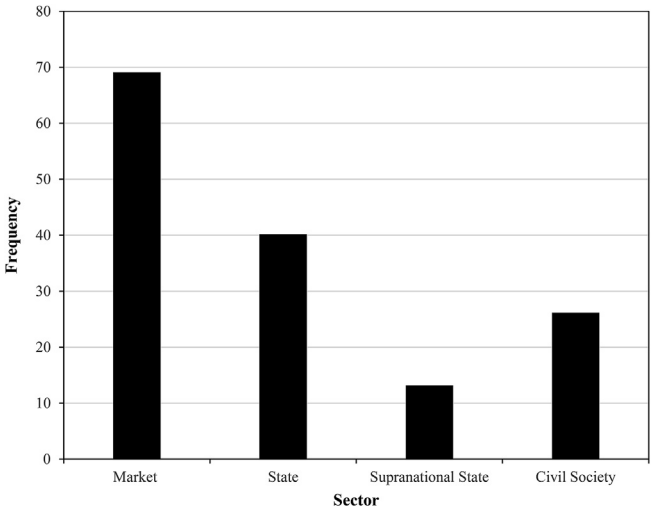

Fig. 6. Column graph showing the frequency of actors within Market, State, Supranational State and Civil Society sectors who have a role in initiating sustainability governance within the electronics value chain, as identified in the scientific literature (1999–2018).

corporate responsibility to address sustainability risks, various states have established extraterritorial legislation[9] to regulate the global activities of domestic MNCs (e.g. section 1502 of the U.S. Dodd-Frank Act; U.K. Modern Slavery Act; French Duty of Vigilance Law).

International and national sustainability frameworks define the standards against which companies can be held accountable and, as shown in Fig. 7 (Zone 4), **market actors** are under increasing pressure from stakeholders[10] to meet these standards (The Enough Project, 2010; Hofmann et al., 2015). In response, market actors are developing and expanding corporate social responsibility (CSR) efforts. The aim of this is not only to increase regulatory compliance but also to manage stakeholder concerns regarding sustainability, in doing so maintaining corporate reputation and brand image (Abbott and Snidal, 2009; Young et al., 2010; Vermeulen and Witjes, 2016). This ***self-governance***[11] approach includes various instruments which differ in scope and purpose but commonly include codes of conduct, product traceability, supplier auditing and reporting, sustainable procurement, as well as sustainability certifications and labels (Vermeulen, 2015; Vermeulen and Metselaar, 2015; Vermeulen and Witjes, 2016). As shown in Fig. 7 (Zone 3), electronics companies have a major role in governing risks across the GVC, in particular, large downstream MNCs[12] who can wield their buying power to influence other market actors (Distelhorst et al., 2015; Jameson et al., 2016; Young, 2018). Moreover, proactive electronics companies have also collaborated to develop collective and more efficient sustainability practices at the industry-level, establishing policy-making bodies, like the Responsible Business Alliance (RBA) to further influence market actors (Prenkert, 2014; Jameson et al., 2016).

Given the role of private actors in sustainability governance and the state leaning towards decentralised approaches, ***public-private*** governance has also emerged due to the interaction between these regimes as shown in Fig. 7 (Zone 4) (Locke et al., 2013; Distelhorst et al., 2015). Strong institutions and rules are required to ensure all actors are cooperative and that private interventions meet required standards (Tong and Yan, 2013; Khetriwal et al., 2007). Yet, this form of governance enables the state to scale back costly management responsibilities, allowing private actors contribute to the resource costs of sustainability management within a controlled and competitive setting (Hagelskjaer and Jørgensen, 2010; Khetriwal et al., 2007).

Although sustainability governance is largely the responsibility for state and market actors, ***interactive governance*** allows multiple actors to participate collectively via horizontal and vertical integration. Within this, **civil society organisations**[13] (CSOs) can be particularly effective in raising awareness of sustainability risks, as well as working directly with brands and governments to support monitoring or standard compliance (Resolve, 2010; Young et al., 2010; Raj-Reichert, 2011; Martin-Ortega, 2018). As shown by Fig. 7 (Zone 7) and Fig. 8, this approach is widely used to govern input-side processes in the GVC, largely due to the complexity of input-side processes. As a result, effective governance requires collaboration between actors to connect local 'on-the-ground' initiatives (often operated by CSOs) with state or markets actor operating on national or international scales. In addition, collaborative arrangements between CSOs have also emerged to monitor and enforce sustainability in a more 'bottom-up' approach (see Zone 6 and 7 in Fig. 7) (Raj-Reichert, 2011). For example, various CSOs with state or industry funding (e.g. GoodElectronics or The Enough Project) are empowering those affected by sustainability risks, representing a partial shift back towards self-governance arrangements. In doing so, echoing Driessen et al. (2012) analysis of shifts in environmental governance, whereby it is continually reworked and built-on, transitioning towards self-governance.

5. Composition of electronics governance

To evaluate the overall effectiveness of sustainability governance in the global electronics value chain, more in-depth analysis focuses how policy instruments and their outcomes (independent variables) influence the overall effectiveness of sustainability governance (dependent variable). These are summarised in Tables 2, 3 and 4.

5.1. Input processes: supply chain governance

Whether due to public, regulatory or industry influence, electronics MNCs are under growing pressure to manage sustainability risks associated with input-side processes (Nadvi and Raj-Reichert, 2015; Young et al., 2010). Yet, electronics brands depend on outsourcing production to various suppliers[14] and are sensitive to the sustainability performance of these companies (Nawrocka, 2008). Consequently, downstream MNCs, especially brand companies, are adopting **measures to monitor and enforce sustainability standards among suppliers** (Young et al., 2010; Distelhorst

[9] Where states can exercise legal jurisdiction beyond the usual limits of national borders, for example when a nation regulates business across their supply chains based on activities or impacts domestically and in foreign countries.

[10] All companies have stakeholders, a term used to define individuals or groups who may affect or be affected by a business' activities.

[11] Self-governance is a broad term and can be initiated by various actors, to distinguish the role of market actors within self-governance this will be referred to as 'market governance' in this article.

[12] Downstream MNCs includes brand companies as well as other large companies involved in the assembly and manufacturing processes (e.g. contract manufacturers).

[13] Civil society includes a broad range of non-profit, non-governmental, research, advocacy and community organisations operating on local, national and international scales.

[14] The outsourcing of electronics production to electronics contract manufacturers and original equipment manufacturers like Foxconn, Pegatron and Flex enables brand companies to reduce manufacturing costs. These manufacturers operate in low cost areas like China and benefit from economies of scale, meaning electronics can be produced and assembled at competitive prices.

Table 1
List of policy instruments used by policy actors at various governance levels for addressing sustainability across the electronics value chain, categorised by sector (i.e. market, civil society and state).

SECTOR	Policy instruments *(associated actors/examples)*
MARKET	**Company level:** *Corporate CSR and supply chain policies* **Industry level:** *Industry standards and codes of conduct (e.g. Responsible Business Alliance; Green Electronics Council; Global e-Sustainability Initiative; International Organisation for Standardisation).*
CIVIL SOCIETY	**National and International level:** *Sustainability campaigns (e.g. Amnesty International; Fair Labour Organisation; Greenpeace; Human Rights Watch, The Enough Project); Electronics campaigns (e.g. Closing the Loop; coolproducts; GoodElectronics Network; Electronics Watch; Global Witness; makeITfair; The Restart Project; Solving the e-waste Problem [STeP] Initiative)*[a].
STATE	**National level:** *State policies (e.g. labour and environmental regulation); extraterritorial regulation (i.e. US Dodd-Frank Act).* **Supranational level:** *EU directives (e.g. WEEE, RoHS); UN frameworks (e.g. Universal Declaration of Human Rights, United National Guiding Principles for Business and Human Rights); ILO standards (e.g. Rights of People at Work); OECD guidelines (e.g. Guidelines for Multinational Enterprises, Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas)*

[a] Sustainability campaigns encompass efforts by CSOs to influence market and state policy at national and/or international levels. Within this electronics campaigns are those conducted by CSOs targeting the electronics value chain specifically.

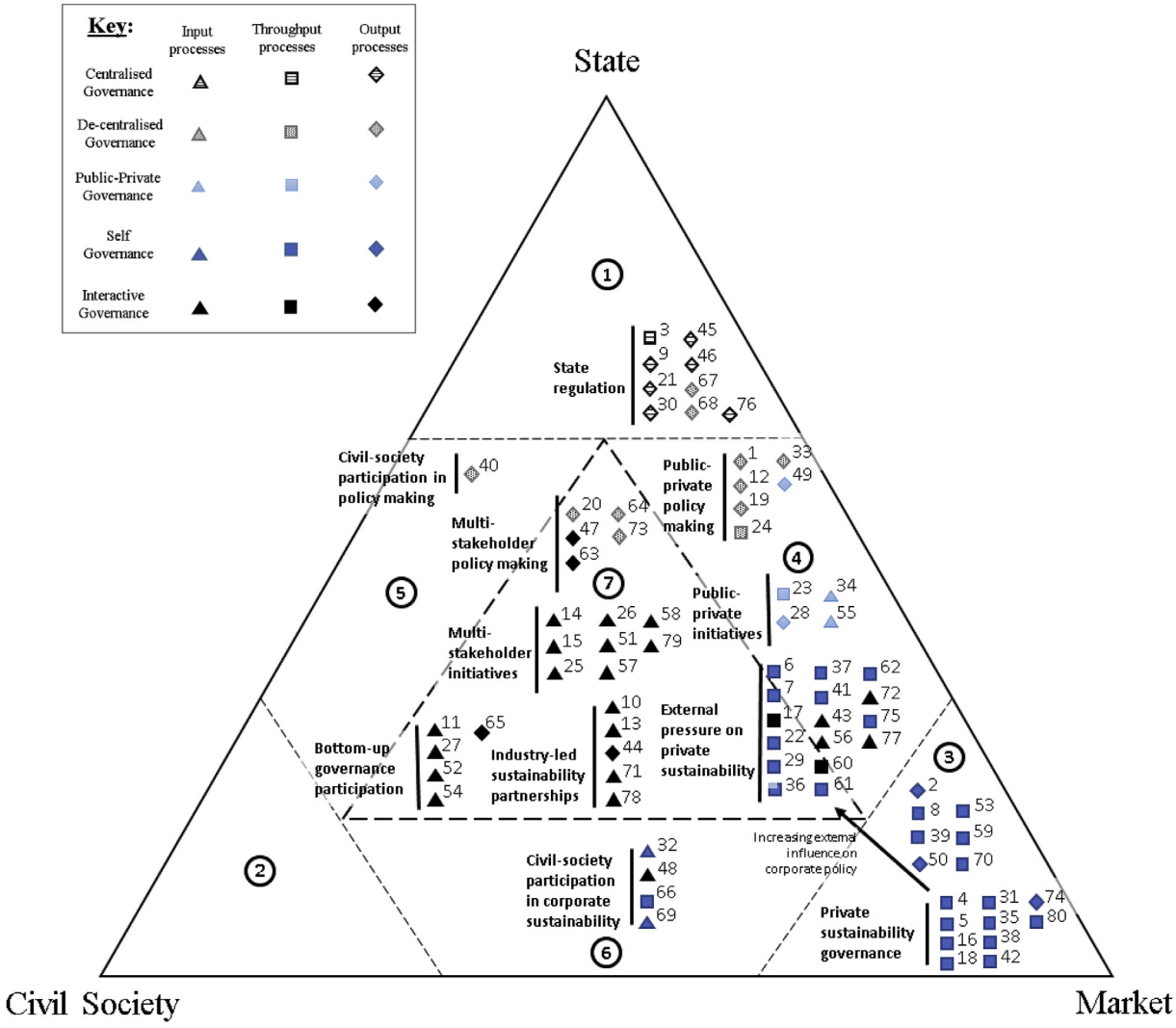

Fig. 7. Governance triangle maps each empirical article (1–80) as a plot point based on the orientation and interaction of policy-actors within State, Market, Civil Society sectors. As shown by the key in the top left: differing shapes of the plot points indicate the stage in the electronics value chain where governance takes place, while differing colours indicate the mode of governance used. Zones numbered 1–7 indicate varying levels of interaction between policy actors within sustainability governance. Plot point references and placement criteria are listed in the *Supplementary Materials*.

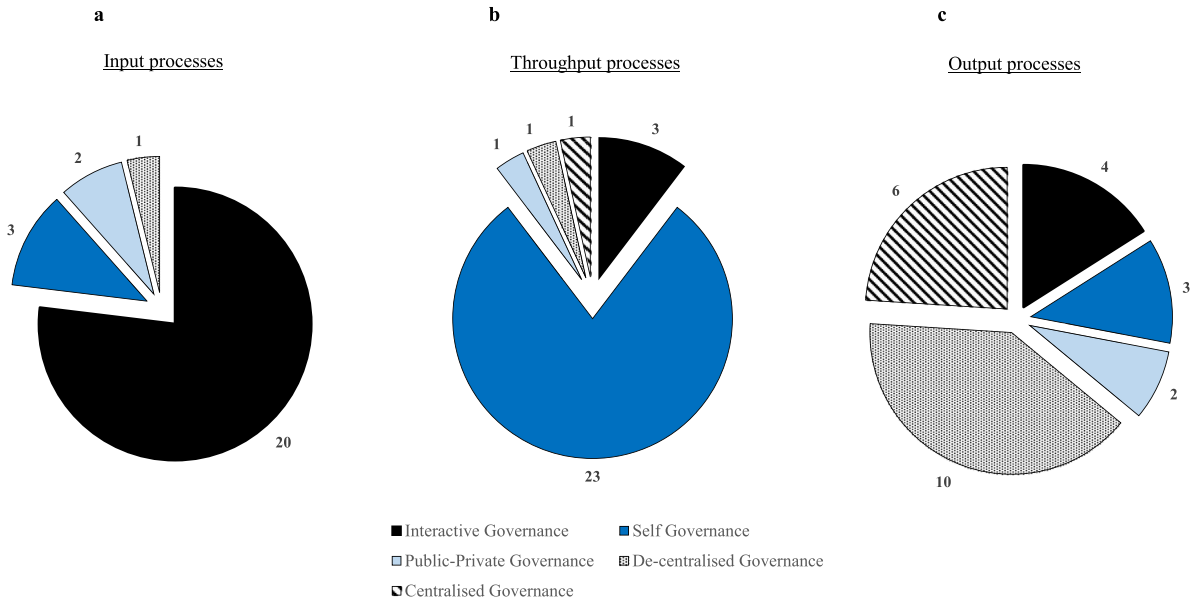

Fig. 8. Pie graphs showing the proportion of each governance mode (i.e. Interactive, Self, Public-Private, De-centralised and Centralised) used to manage sustainability risks in the electronics value chain, as identified in the empirical literature (1999–2018). Results are grouped into three graphs based on the governance modes used at each stage of the electronics value chain and are arranged in the following order: input processes (*left*); throughput processes (*middle*); and output processes (*right*).

Table 2
Synthesis of independent variables affecting input-side processes within each empirical article (1–80), categorised by mode of governance. See Supplementary Materials for article number references.

ARTICLE(S) [a]	GOVERNANCE MODE	INDEPENDENT VARIABLES (AFFECTING INPUT-SIDE PROCESSES)[b]
10, **11**, 15, *25*, **26**, **34**, **43**, **48**, **54**, **55**, **56**, **58**, **60**, *69*, **71**, **72**, **77**, **78**, **79**	*Centralised*	+ institute transnational corporate responsibilities - lack of transnational solution for root causes of sustainability risks - undermine local social-economic development
11, **13**, **14**, *15*, 26, **27**, *34*, 43, **51**, *52*, *54*, **55**, *57*, 58, *72*, *77*, **79**	*Decentralised*	+ define national governance/development frameworks - fall below recognised sustainability frameworks - weak governance and/or corruption in developing nations
10, **15**, *25*, **26**, **27**, **34**, **39**, *43*, **55**, *56*, *60*, **69**, *71*, **72**, **78**	*Public-Private*	+ complimentary public-private governance + public sector support and resources + synergy with local governance
10, 11, **13**, **14**, **15**, **16**, **25**, *26*, 27, **32**, 34, **39**, **43**, **48**, **51**, 52, 54, *55*, **56**, 57, 58, 60, **71**, *72*, *77*, **78**, **79**, **80**	*Self-governance*	+ corporate sustainability standards and risk management + industry-level cooperation and exchange - market pressures for cheap and fast production - resource, experience and financial limitations
10, **11**, **13**, **14**, *15*, **25**, **26**, **27**, **32**, 34, **43**, **48**, **51**, **52**, **54**, **56**, **57**, **58**, *60*, **69**, **71**, **72**, *77*, **78**, **79**	*Interactive (multi-stakeholder)*	+ capacity building and increased risk awareness + diverse and legitimate solutions - over-simplification of costs and barriers - lack of electronics supply chain transparency
14, *15*, 48, *52*, *54*, *58*, *69*, *77*, **78**, **79**	*Interactive (bottom-up)*	+ strategic action and campaigns against misconduct + local incorporation into political/industrial reform - ideological and structural barriers to engagement

[a] Differing emphasis within each empirical article on the governance mode required by policy-level actors for improved sustainability outcomes is indicated by article number fonts: **Bold** = recommended mode; *italic* = recommended mode but improvements are required; underlined = this mode negatively affects sustainability.
[b] Positive and negative impacts of each independent variable on the associated dependent variable are indicated with + or -.

et al., 2015; Nadvi and Raj-Reichert, 2015). These companies can use their purchasing power and leverage to establish mandatory sustainability monitoring and reporting among suppliers (i.e. supply chain due diligence[15]) (Distelhorst et al., 2015; Jameson et al., 2016; Young, 2018). By incorporating due diligence into supplier relations, electronic products and the sustainability risks linked to their production can be more effectively tracked and managed (Distelhorst et al., 2015; Jameson et al., 2016). Industry associations have also developed programs to tackle electronics sustainability risks (e.g. Responsible Minerals Initiative and Responsible Factory Initiative established by the RBA) (Raj-Reichert, 2011; Distelhorst et al., 2015; RBA, 2019). These facilitate **cooperation at the industry-level** by providing platforms for linking downstream and

[15] Supply chain due diligence is a system for incorporating the monitoring and reporting of risks into suppler relationships, where supply chain actors across the GVC have a responsibility to identify, assess and address relevant risks while also collaborating with relevant suppliers and buyers.

upstream companies, thus reducing the complexity and costs involved in supply chain due diligence (Resolve, 2010; Young et al., 2010; Raj-Reichert, 2011; Jameson et al., 2016).

Yet, it remains challenging for companies to manage suppliers throughout the geographically disperse input-side stages of the GVC, particularly where corruption, structural problems or political conflict undermine state regulatory capacity and authority (Resolve, 2010; Young et al., 2010; Distelhorst et al., 2015; Martin-Ortega et al., 2015; Jameson et al., 2016). For example, limited state provisions to protect artisanal miners in countries like the Democratic Republic of the Congo[16] has resulted in severe sustainability concerns including hazardous work, child labour and illegal taxation funding on-going political conflict (Hofmann et al., 2015; Amnesty International, 2016; Callaway, 2018). Moreover, minerals from unsustainable sites mix with those that are regulated, making it difficult to discern the sustainability of minerals used in electronics products downstream (Resolve, 2010; Young et al., 2010; Jameson et al., 2016).

Furthermore, brand companies driven by high-profit margins put pressure on suppliers for fast, cheap and quality outputs (Distelhorst et al., 2015; Nadvi and Raj-Reichert, 2015). Additional **market pressures** such as rapid changes in technology and demand put further capacity and financial stress on suppliers (Raj-Reichert, 2011; Distelhorst et al., 2015; Nadvi and Raj-Reichert, 2015). Resulting in endemic sustainability concerns in mining and manufacturing areas, including poor health and safety standards, excessive or forced labour, as well as coercion and abuse of workers (e.g. CBBRC, 2015; Martinez, 2015; CEREAL, 2016; Chan et al., 2016). Moreover, limited worker representation (e.g. grievance mechanisms, trade unions, collective bargaining) in many countries means that sustainability concerns are often disregarded by company and state authorities; students, temporary and migrant workers are particularly vulnerable because of this (Evermann, 2014). Furthermore, efforts by MNCs to enforce sustainability standards among suppliers are not always successful due to the complexity and number of suppliers in the GVC (China Labour Watch, 2017). This approach can also push the responsibility for implementing sustainability measures onto suppliers, who often lack **technical resources, experience and finance** without adequate support from larger downstream companies or industry associations (Nawrocka, 2008; Resolve, 2010; Young et al., 2010; Raj-Reichert, 2011; Nadvi and Raj-Reichert, 2015).

To address this, statutory standards for corporate sustainability have emerged in consumer markets, aiming to prevent domestic MNCs from contributing to sustainability risks abroad (Amnesty International, 2016). These policies have increased corporate compliance to sustainability criteria regarding conflict minerals (i.e. US Dodd-Frank Act) and manufacturing standards (i.e. EU Public Procurement directive) (Nadvi and Raj-Reichert, 2015; Jameson et al., 2016). However, some authors are concerned about the limited scope of current legislation at the state level, which **falls below sustainability frameworks** outlined by the UN and OECD (Martin-Ortega et al., 2015; Nadvi and Raj-Reichert, 2015; Global Witness, 2016; Jameson et al., 2016). Furthermore, legislation in consumer markets does **not provide an effective solution for the root causes of sustainability risks** in developing countries, allowing weak governance and political corruption to continue (Raj-Reichert, 2011; Jameson et al., 2016). On top of this, legislation has fashioned a bad image for materials or products coming from certain regions (i.e. minerals from central Africa), potentially **undermining social and economic development** associated with legitimate trade in these goods (Jameson et al., 2016).

Despite this, Distelhorst et al. (2015) demonstrate that **public-private governance can act in a complementary manner**, whereby market governance is dependent on and aided by legitimate state regulation while also ensuring compliance to sustainability standards in areas of weak regulation. Furthermore, partnering private initiatives with external agencies, governments, and international organisations, can provide **funding, resources, staff**, and ensure **strategies work within local governance and development frameworks** (Resolve, 2010). For example, the OECD provides internationally recognised frameworks to support responsible supply chains (e.g. Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas) (Jameson et al., 2016). This stresses that increasing supply chain transparency via cooperation and sharing of supply chain information (e.g. audit reports, factory locations, mineral sources) between stakeholders, can support risk monitoring and management (OECD, 2013). For example, by **allowing independent actors to participate** in supply chain monitoring (e.g. Electronics Watch), as well as working with CSOs on-the-ground to identify and manage risks (e.g. workers unions) (Resolve, 2010; Young et al., 2010; Raj-Reichert, 2011; Distelhorst et al., 2015). Formalised multi-stakeholder groups can increase this collaboration, connecting in-region initiatives which verify and address sustainability risks with international organisations and companies focused on developing responsible supply chains (e.g. the European Partnership for Responsible Minerals). Contributing to more **diverse and legitimate solutions at the local level** (Resolve, 2010; Martin-Ortega et al., 2015; Jameson et al., 2016).

CSOs also operate collectively in a bottom-up manner to monitor and enforce standards (Raj-Reichert, 2015). For example, GoodElectronics is an EU funded network of worker unions, researchers and activist groups, which engages with brand companies and state representatives to **raise awareness of sustainability risks and campaign against corporate misconduct** (Raj-Reichert, 2011). Moreover, incorporating those affected by sustainability risks can provide a foundation with which to propagate **reforms for addressing local governance in high-risk areas** (Jameson et al., 2016). For example, traceability initiatives can be used to advocate for the rights of adversely affected stakeholder, while also incorporating them into wider development initiatives (*ibid*). However, these approaches are criticised for being **over-ambitious, resource-intensive** and **failing to recognise the lack of influence MNCs have upstream in the GVC** (Young et al., 2010). Moreover, CSOs face challenges engaging with the industry and self-organising. This stems from **limited supply chain transparency**, **ideological differences** relating to a lack of industry support for unions, as well as the **structural difficulties** organising stakeholders across diverse social, geographical, cultural and legal backgrounds (Raj-Reichert, 2011; Locke et al., 2013).

5.2. Throughput processes: corporate sustainability governance

Market governance of sustainability has an increasingly important role in governing sustainability across the GVC, particularly among electronic brand companies. These companies are responding to increasing public demand for CSR measures, as well as an intensification of CSR requirements enforced by governments, international organisations and industry bodies at various scales (Chien and Shih, 2007; Nawrocka, 2008; Lee and Kim, 2009; Wittstruck and Teuteberg, 2012). In addition to external factors 'pushing' companies to adopt CSR measures, various 'pull' factors also encourage companies to invest in CSR. For example, successfully implemented CSR can deliver improved stakeholder

[16] Informal mining in among the largest employers globally, creating economic opportunities for 10% of the population in the Democratic Republic of the Congo and directly employing around 2 million people (Callaway, 2018).

Table 3
Synthesis of independent variables affecting throughput processes within each article (1–80), categorised by mode of governance. See Supplementary Materials for article number references.

ARTICLE(S)	GOVERNANCE MODE	INDEPENDENT VARIABLES (AFFECTING THROUGHPUT PROCESSES)
6, **7**, **17**, **22**, **24**, **29**, **36**, **37**, **41**, **53**, **57**, **61**, **77**, **80**	*Centralised*	+ development of sustainabiltiy norms and standards - limited influence at higher ends of the GVC
3, **6**, *7*, **13**, *23*, *37*, **41**, **53**, **59**, **60**, **61**, **62**, **75**	*Decentralised*	+ industrial sustainability requirements - limited scope across the GVC
3, **4**, *5*, **6**, *7*, **8**, **10**, **13**, *16*, *17*, **18**, **22**, **23**, *24*, **29**, **30**, **31**, **35**, **36**, *37*, *38*, *39*, **41**, **42**, *53*, **54**, *59*, *61*, *62*, *66*, 75, **76**, **80**	*Self-governance (company-level)*	+ top management support and commitment + internal information networks and sustainability infrastructure + increase competitive advantage + improved supply chain relationships - technical, financial, cultural and risk barriers - pursuit of short-term profit can motivate sustainabiltiy goals
6, *17*, **23**, **31**, *38*, *61*, **70**, *75*	*Self-governance (industry-level)*	+ reduce barriers to corporate-level self-governance + universal sustainability standards, guidance and tools - limited impact on sustainability in high-risk areas
6, **7**, **8**, **10**, **17**, **22**, **24**, **29**, **31**, **36**, **37**, **38**, **41**, **53**, **60**, **61**, **62**, **66**, **75**	*Interactive*	+ strategic collaboration to improve corporate knowledge and innovation + consumer and advocacy pressure for sustainability - technical, financial and risk constraints

relationships, enhance company/brand image, reduce costs through efficiency savings, as well as increase competitive advantage and market-share growth (Chien and Shih, 2007; Nawrocka, 2008; Lee and Kim, 2011; Wittstruck and Teuteberg, 2012; Wong, 2013; Hofmann et al., 2015). Such positive effects can also be enhanced via **stakeholder engagement** (e.g. sustainability reporting), enabling companies to promote successful CSR activities and better understand or meet stakeholder expectations (Chien and Shih, 2007; Wittstruck and Teuteberg, 2012; Hsu and Chang, 2017). As a result of these **market, regulatory and social pressures**, companies now recognise the strategic value of sustainability. Companies like Hewlett-Packard, Apple and Intel have emerged as industry leaders (see Callaway, 2017; Deberdt and Jurewicz, 2018; KnowTheChain, 2018). Such companies incorporate recognised sustainability standards, frameworks and certifications into corporate policies to add credibility and demonstrate commitment[17] (Lee and Kim, 2009).

Despite this, the level of commitment and compliance to sustainability standards varies between companies and forms part of a broader sustainability spectrum in the electronics industry. However, literature shows us that companies with clear commitments to recognised sustainability standards are generally better at engaging with stakeholders as part of communicating, planning and managing sustainability (see The Enough Project, 2010; Deberdt and Jurewicz, 2018; KnowTheChain, 2018). This is important because brand companies are critically dependent on various market actors to implement sustainability standards on both the input and output sides of the GVC (Nawrocka, 2008; Lee and Kim, 2009). Therefore, engagement with relevant market actors is vital for establishing systems for coordinated and harmonised governance (Lee and Kim, 2011; Wittstruck and Teuteberg, 2012). For example, incorporating sustainability standards into supplier requirements can be used to promote sustainability monitoring and reporting down the GVC, especially if suppliers require sub-suppliers to meet the same sustainability standards (Lee and Kim, 2009; Raj-Reichert, 2011; Wittstruck and Teuteberg, 2012). As part of this, establishing **long-term and collaborative relationships with market actors** is vital to build capacity and strengthen trust among market stakeholders, supporting increased commitment to effective sustainability management (Lee and Kim, 2011; Wittstruck and Teuteberg, 2012; Wong, 2013). This management of market actors is also vital for governing output-side sustainability risks and complying to product-related regulatory requirements like the RoHS and WEEE directives (Lenox et al., 2000; Lee and Kim, 2011). For example, collaborating with consumers, suppliers and recyclers is critical for developing more sustainable electronics (e.g. increasing product lifespan, using recycled materials, increasing recyclability) and altering manufacturing or take-back processes to incorporate these changes (Lee and Kim, 2011; Govindan et al., 2013; Wong, 2013).

The effective management of external stakeholders within sustainability governance is also influenced by various endogenous factors linked to business location, size and product type, as well as internal culture, structure and governance (Nawrocka, 2008; Law, 2010; Lee and Kim, 2011; Wong, 2013; Liu et al., 2015). For example, **top management support and commitment** are vital for embedding sustainability criteria into corporate policy and decision-making (Lenox et al., 2000; Law and Gunasekaran, 2012; Wittstruck and Teuteberg, 2012; Govindan et al., 2013; Wong, 2013). Within this, the development of **internal information networks** is vital for the vertical communication of sustainability risks to executive staff, while also diffusing sustainability responsibilities horizontally across corporate departments for procurement, marketing, product design, supplier management, distribution and take-back (Chien and Shih, 2007; Lee and Kim, 2011; Wittstruck and Teuteberg, 2012; Wong, 2013). **Developing internal infrastructure** for sustainability governance (e.g. a cross-functional sustainability team) can support this by facilitating planning, strategy and communication (internally and externally). In doing so, increasing the efficiency with which relevant actors are incorporated into sustainability governance, while also providing support or training to improve their effectiveness (Lenox et al., 2000; Wittstruck and Teuteberg, 2012; Govindan et al., 2013; Wong, 2013; Hsu and Chang, 2017). Although, many **brand firms lack the organisational commitment, finances, personnel, expertise and/or leverage over suppliers** to effectively implement sustainability management (Nawrocka, 2008; Lee and Kim, 2011;

[17] These outline corporate responsibilities for the management of environmental impacts (ISO 14001), occupational health and safety (OHSAS, 18001), sustainability auditing and reporting (AA 1000; SA 8000; Global Reporting Initiative), as well as broader sustainability frameworks established by state organisations (e.g. EU, UN, OECD, International Labor Organisation).

Table 4
Synthesis of independent variables affecting output-side processes within each article (1–80), categorised by mode of governance. See Supplementary Materials for article references.

ARTICLE(S)	GOVERNANCE MODE	INDEPENDENT VARIABLES (AFFECTING OUTPUT PROCESSES)
19, **20**, 22, **26**, **30**, **45**, **47**, *49*, **63**, **64**, **67**, **73**, *76*	*Centralised*	+ roles and responsibilities for e-waste on an international scale + e-waste standards, labels and certifications - lack of supply chain transparency
1, *9*, **12**, **19**, *20*, 21, 22, *26*, *28*, *30*, **33**, *40*, *44*, **45**, *46*, **47**, *49*, *50*, *63*, *64*, *65*, **67**, *68*, **73**, **74**, *76*	*Decentralised*	+ regulatory and administrative capacity + definition of stakeholder e-waste management roles - weak e-waste governance in developing nations - limited public resources for e-waste management
1, *9*, **12**, **19**, **20**, **30**, **33**, **46**, *49*, **63**, **67**, *68*, *76*	*Public-Private*	+ market-based competitiveness and efficiency - monopolising, uncooperative and free-riding actors
1, **2**, 9, **12**, **19**, **20**, **22**, **28**, **30**, **33**, **40**, **41**, **47**, **49**, *50*, **59**, **63**, **64**, **65**, **67**, **68**, **73**, **74**, **76**	*Self-governance*	+ sustainable product design and manufacturing - unsustainable production and consumption patterns - uncontrolled and often illegal export of second-hand e-waste
1, **9**, **12**, **20**, **21**, **26**, **28**, **40**, **44**, **47**, **50**, **63**, **64**, **65**, **67**, **68**, **73**	*Interactive*	+ training, technology transfer + capacity building + independent monitoring and control + research and educational programs - increased transaction and resource costs

Wittstruck and Teuteberg, 2012; Wong, 2013). Furthermore, various exogenous factors influence sustainability governance due to the numerous actors involved at various tiers in the GVC, creating various challenges for brand companies. For example, sustainability standards are more difficult to enforce and less widely implemented among distant suppliers (Nawrocka, 2008; Raj-Reichert, 2011). These indirect suppliers operate at higher tiers in the GVC and often in countries with low sustainability standards, meaning they are under less pressure from market, government and public stakeholders to participate in sustainability governance (*ibid*). Moreover, without adequate downstream support, **smaller upstream companies often lack the capabilities or incentives to participate** (*ibid*).

To address this, **industry organisations can facilitate sustainability management across the GVC**. For example, the RBA aggregates leverage among downstream firms and uses this to coax other market actors into sustainability management initiatives. As part of this, the RBA also provide smaller upstream companies with sustainability management training and resources, while establishing industry-wide sustainability requirements and platforms for sharing information[18] (Chien and Shih, 2007; Raj-Reichert, 2011; Liu et al., 2015). Overall, this **reduces the complexity and transaction costs** involved in corporate sustainability management, while also strengthening trust between market actors. In doing so, establishing a **standardised approach across the industry** and pooling collective resources to promote sustainability management (Resolve, 2010; The Enough Project, 2010; Raj-Reichert, 2011; Wittstruck and Teuteberg, 2012; Jameson et al., 2016; Young, 2018). Although, these organisations are criticised for promoting a "lowest common denominator response [regarding sustainability]"(The Enough Project, 2010, p. 2). This often **only seeks to promote sustainability as a way to increase competitive advantage**, rather than pursuing long-term sustainability or addressing deep-rooted political, cultural and economic problems across the GVC (Chien and Shih, 2007; Raj-Reichert, 2011; Prenkert, 2014; Jameson et al., 2016). Consequently, there is a need to encourage laggard companies to adopt sustainability management, while also establishing stricter sustainability regulations and norms.

5.3. Output processes: e-waste governance

E-waste is one of the fastest-growing waste streams, with an estimated 65 million tons generated globally in 2017 (Herat, 2007; International Labour Organisation, 2014; Heacock et al., 2018). Yet, e-waste is problematic because it contains toxic substances which pose a danger to health and the environment if not dismantled and disposed of correctly (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010; Heacock et al., 2018). To address this, comprehensive policy frameworks have emerged to **regulate and enforce e-waste management** at national and municipal levels (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010; Tong and Yan, 2013). For example, the EU's WEEE directive **defines national stakeholder roles in WEEE management** (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010). The general approach is to develop public institutions to oversee WEEE management while using the principle of extended producer responsibility (EPR) to ascribe economic responsibility for WEEE management to downstream electronics companies (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010; Tong and Yan, 2013). In doing so, EPR obligates that private organisations finance and manage a **market-based system of WEEE take-back, recycling and disposal**, incorporating electronics brands, retailers, consumers, waste collectors and recyclers (Khetriwal et al., 2007; Tong and Yan, 2013). This formalised 'reverse logistics' system operates within the sphere of government support and regulation but **provides additional resources and capacity** from the private sector (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010). While the WEEE directive and principle of EPR are obligatory to EU member states, governments in China, Japan and South Korea have also used these to **frame e-waste management policy** and develop parallel policies (Khetriwal et al., 2007; Tong and Yan, 2013). Moreover, EU directives on RoHS (2011/65/EU) and Ecodesign (2005/32/EC) operate in parallel with WEEE management, stressing EU market entry requirements for electronics products. Thus, reinforcing long-term e-waste management by outlining the need for **sustainable product design and manufacturing processes** (Nnorom and

[18] The RBA standards and guidance incorporate international frameworks like ISO 14001, OHSAS 18001 and those established by the OECD (e.g. Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas), UN (e.g. Guiding Principles on Business and Human Rights), and International Labor Organisation (e.g. Declaration on Fundamental Principles and Rights at Work).

Osibanjo, 2008; Hagelskjaer and Jørgensen, 2010)

Despite the increased efficiency and volume of e-waste recycling due to EPR policies, they are criticised for **not addressing unsustainable manufacturing and consumption patterns** which perpetuate sustainability risks across the GVC (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010). This is compounded by the weak definition of sustainability and lack of incentives for increasing electronics sustainability by prolonging product lifespan or durability (Manomaivibool, 2009; Pickren, 2014). Additionally, to achieve an efficient management system, EPR depends on stakeholder compliance and smooth transactions between actors. This can be undermined by **monopolising, uncooperative and free-riding behaviour** among stakeholders, particularly those who do not wish to bear the costs of recycling (Khetriwal et al., 2007; Tong and Yan, 2013). Fees involved in the enforcement and control of actors may also undermine any state savings in this market-system (Hagelskjaer and Jørgensen, 2010). Furthermore, market policies like the WEEE directive are criticised for incentivising the **export of e-waste (often illegally) to low cost and unregulated sites in developing countries**[19] (Nnorom and Osibanjo, 2008; Tong and Yan, 2013; Heacock et al., 2018). Within this trade, e-waste is trafficked by criminal groups and sold to small-scale informal recyclers who extract small quantities of valuable metals (Geeraerts et al., 2015; Heacock et al., 2018). While the informal sector provides an independent mechanism for reclaiming these metals, this is often conducted by vulnerable groups and children in areas where technology, infrastructure and environmental or safety considerations are limited (Nnorom and Osibanjo, 2008; International Labour Organisation, 2014; Heacock et al., 2018). Furthermore, to be cost-effective crude and inefficient processes are used, like burning and use of acids, which contribute to environmental pollution and health issues (*ibid*).

Transitioning towards formalised e-waste management in developing nations can reduce sustainability risks associated with e-waste, yet there is a need to incorporate informal actors who derive economic opportunities from this industry (Nnorom and Osibanjo, 2008; ILO, 2014; Pickren, 2014; Heacock et al., 2018). Here, CSOs such as the StEP initiative can support improvements in the informal sector by providing **training (of informal workers), technology and capacity building** to facilitate safe recycling practices and clean-up of polluted recycling sites (*ibid*). There is also a need to prevent the wholesale trade and dumping of e-waste on informal markets in developing countries. Authors outline the role of **WEEE certifications and regulations** in engaging with production and consumption processes at the international scale. The EU's Eco-design and RoHS directives are good examples and aim to address sustainability at the product design and manufacturing stages, reducing EoL risks (ILO, 2014; Pickren, 2014). However, it remains challenging to translate EPR policies into developing countries (Khetriwal et al., 2007; Nnorom and Osibanjo, 2008). This is undermined by a **lack of corporate transparency** regarding product design (i.e. chemicals used in electronic products), as well as an oversimplification in current policies regarding what e-waste is, where it goes, and how it should be managed (Pickren, 2014; Cook and Jardim, 2017). Despite this, incorporating various stakeholders (e.g. consumers, recyclers, producers, retailers) into national and international governance can counteract this complexity, ensuring **independent monitoring** among various actors and **building e-waste management capacity** across the GVC (Khetriwal et al., 2007). Furthermore, CSOs like makeITfair use **research and educational programs** to lobby for policy improvements, confront producers regarding product sustainability, as well as inform the public about sustainable e-waste management (ILO, 2014; Hagelskjaer and Jørgensen, 2010).

[19] China, India, Mexico, Ghana and Nigeria are among the countries which receive the highest volumes of e-waste, some of which is sold into second-hand markets while the majority is processed informally to extract valuable metals or reusable parts. The volume of this illegal e-waste trade is difficult to quantify due to its concealed nature and has not been accurately measured, yet, research suggests that 8 million tonnes a year are smuggled from the EU to China alone (Geeraerts et al., 2015).

6. Electronics governance effectiveness

Based on analysis of the structural and compositional qualities of sustainability governance in the literature and how these contribute to effective outcomes, this section critically examines the overall effectiveness of each governance mode in each stage of the global electronics value chain (summarized in Table 5).

Firstly, decentralised governance is most effective among developed countries when instigated by state institutions with the administrative capacity and authority to define and enforce stakeholder responsibilities; the regulation of e-waste within developed economies is a good example (see Figs. 7 and 8). Many countries also outline extraterritorial regulations which influence corporate management or reporting of sustainability, encouraging electronics brands to implement sustainability measures with market actors across the GVC (Raj-Reichert, 2011; Distelhorst et al., 2015; Jameson et al., 2016). Despite this, there are calls to reform or improve policies to be more effective, including incentivising stakeholder engagement in more long-term policymaking (Nawrocka, 2008; Wong, 2013; Jameson et al., 2016), adhering to recognised international sustainability frameworks (e.g. Martin-Ortega et al., 2015; Nadvi and Raj-Reichert, 2015), and addressing sustainability concerns in an integrated international approach (Nnorom and Osibanjo, 2008).

Supranational and international organisations have a role here in a more centralised governance approach. This includes harmonising national sustainability policy between states (i.e. EU directives), as well as putting pressure on market actors to accept accountability for negative impacts across their supply chains (i.e. UN and OECD standards) (Hagelskjaer and Jørgensen, 2010; The Enough Project, 2010; Hofmann et al., 2015; KnowTheChain, 2018). Although, some authors raise concerns about the lack of enforceability and cohesion between international sustainability frameworks (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010; Martin-Ortega et al., 2015). Consequently, state and market actors often fail to implement them effectively and the overall impact of centralised governance is difficult to measure (Locke et al., 2013; Martin-Ortega et al., 2015; Jameson et al., 2016; Cook and Jardim, 2017). Despite this, organisations like the UN or OECD have the collective influence to establish statutory and non-statutory regulations across the GVC; including CSR standards, guides and norms, as well as regulating product requirements in consumer markets.

Market governance among electronics brands is critical for sustainability, as shown in Fig. 7. These MNCs are the most influential actors in the GVC and their corporate sustainability policies can substitute for national laws in areas of weak state governance (Locke et al., 2013). Furthermore, industry organisations such as the RBA have emerged to support the process of self-regulation in a variety of ways (Raj-Reichert, 2011; Liu et al., 2015). Yet, many companies fall short of industry leaders due to market pressures, as well as the financial and technical limitations of managing sustainability within a wide supplier base (Vermeulen and Kok, 2012; Wittstruck and Teuteberg, 2012; Wong, 2013; Distelhorst et al., 2015; Nadvi and Raj-Reichert, 2015). Moreover, companies less exposed to public pressure (i.e. at remote tiers in the GVC) or those lacking resources and support from within the industry, often fail to

Table 5
Table showing the extent to which governance modes identified achieved effective sustainability governance at each stage of the electronics value chain, with values based on total article scores[a]. These values are combined to calculate the overall impact of each governance mode on sustainability across the electronics value chain.

GOVERNANCE MODE	INPUT PROCESSES	THROUGHPUT PROCESSES	OUTPUT PROCESSES	SUSTAINABILITY IMPACT
Centralised	33	28	21	Medium
Decentralised	15	22	30	Medium
Self-governance	27	49	44	High
Public-Private	24	0	22	Low
Interactive	52	42	34	High

[a] As per methodology, effective governance modes score 2; semi-effective modes needing improvement score 1; and those that negatively affect sustainability score −1 (see Tables 2–4).

implement sustainability measures (Lee and Kim, 2011; Wong, 2013). The literature also points to a lack of willingness within the industry to increase supply chain transparency and engage with external stakeholders (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010; Raj-Reichert, 2011). Despite this, market governance among companies has driven improvements in sustainability performance across the GVC. This includes monitoring and enforcing sustainability standards, as well as internal management of the electronics design, logistics, procurement and disposal processes (Wong, 2013).

To address the problems of corporate and state approaches, some authors call for partnerships between public and private actors (Distelhorst et al., 2015). For example, the EU's WEEE directive has resulted in formally regulated and efficient systems for sustainable waste management (Khetriwal et al., 2007; Tong and Yan, 2013). Despite this, formal public-private governance is not commonplace in the global electronics value chain. This can be attributed to various factors, including a lack of state capacity to regulate the private sector in high-risk areas (Khetriwal et al., 2007; Nnorom and Osibanjo, 2008); a lack of willingness from state and industry bodies to engage with other stakeholders (Khetriwal et al., 2007; Hagelskjaer and Jørgensen, 2010; Raj-Reichert, 2011); and broad challenges integrating state and corporate policies in such a complex regulatory landscape (Locke et al., 2013; Distelhorst et al., 2015).

Finally, interactive approaches have a role in governing sustainability within the global electronics value chain, especially where state and market actors fail to meet sustainability standards (Raj-Reichert, 2011; Jameson et al., 2016). Consequently, many authors argue that interactive approaches between multiple stakeholders are most effective, primarily as a way of sharing knowledge, resources or governance roles between actors at various governance levels (Resolve, 2010; Prenkert, 2014; Jameson et al., 2016). Formalised multi-stakeholder arrangements can benefit from a greater degree of collaboration between actors at local, national and international scales. Thus, increasing the capacity and impact of sustainability initiatives, while also extending them to address complex and entrenched sustainability risks in high-risk areas (Khetriwal et al., 2007; Resolve, 2010; Young et al., 2010; Raj-Reichert, 2011; Distelhorst et al., 2015). However, entrenched power structures, limited supply chain transparency and ideological differences between stakeholders are major barriers to multi-stakeholder engagement (Raj-Reichert, 2011). Because of these barriers, multi-stakeholder initiatives are not fully inclusive or established in the electronics global value chain.

7. Implications of this study for industry, state and civil society stakeholders

The purpose of this article is not to conduct new empirical research but to reflect and bring together a range of academic perspectives to generate a holistic understanding of the electronics value chain, reflecting the study of relationships between state, corporate and civil society actors within environmental governance (Abbott and Snidal, 2009; Driessen et al., 2012). In doing so, this article has highlighted the main challenges confronting the governance of sustainability within the electronics GVC. The primary challenge being regulating complex relationships between actors within the GVC, who are also distributed globally across the fractured tiers of the GVC which includes raw material sourcing (input), manufacturing/consumption (throughput) and disposal (output). Consequently, sustainability governance consists of a *milieu* of actors, institutions and instruments which are interrelated but often act separately by independently governing sustainability issues across the GVC, while also operating at different scales and locations.

Despite this fragmentation of governance responsibilities, there remain opportunities for new approaches to evolve (Abbott and Snidal, 2009; Vermeulen, 2010; Fransen and Conzelmann, 2015). Within this, many authors recognise the potential of emerging and innovative governance arrangements as a way to push sustainability beyond current standards or obligations (Resolve, 2010; Driessen et al., 2012; Jameson et al., 2016; Martin-Ortega, 2018). For example, while state actors and electronics brands are principally responsible for electronics sustainability governance, collaborative forms of governance can harmonise aspects of centralised, decentralised and corporate governance within an interactive approach (see KnowTheChain, 2018). Such interactive approaches can benefit from the resources, global influence and regulatory power of state and market actors while allowing CSOs to provide expert knowledge, independent monitoring and links to affected stakeholders on-the-ground. Moreover, linking local, national and international actors in this way enables actors to share responsibilities and increase capacity, as well as developing broader and cohesive approaches to governance which address sustainability risks across the GVC.

Many pro-active electronics brands have sought to incorporate interactive approaches into their supply chain sustainability measures. Many other electronics companies participate in industry bodies such as the RBA, which have established industry-wide standards incorporating multi-stakeholder sustainability measures derived from the UNGPs, ILO, OECD and government legislation (The Enough Project, 2010; Raj-Reichert, 2011). Yet, research by Global Witness (2017) and KnowTheChain (2018) shows that among electronics companies there is a disconnect between corporate sustainability policies, their implementation, and the public reporting; a relationship compounded by the interpretive and often voluntary nature of standards like the Due Diligence Guidance. For example, in 2018 only 45% of 3 TG exporting companies in the DRC published due diligence reports, despite it being a legal requirement in the DRC and part of supply chain transparency policies like Dodd-Frank Act (Global Witness, 2017). This lack of leadership and willingness to increase supply chain transparency with external stakeholders can undermine multi-stakeholder

interaction (Overeem, 2009; Evermann, 2014; Cook and Jardim, 2017). Even industry initiatives like the RBA show signs of failing to engage with CSOs on an equal and long-term basis, in large part due to ideological differences on issues like freedom of association and worker empowerment (Raj-Reichert, 2011; Fransen and Conzelmann, 2015). As a result, corporate sustainability measures often lack verification by independent stakeholders, leading to mistrust of market governance among CSOs (Overeem, 2009).

In this context, Ostrom's studies of polycentric governance highlight that trust-building and reciprocal agreements can facilitate mutual learning, cooperation and commitment within environmental governance (Ostrom, 2010). It is the opinion of the authors that the electronics sector should take lessons from other industries, like the garment sector, where established multi-stakeholder initiatives are used to address sustainability risks in global supply chains (Overeem, 2009; Fransen and Conzelmann, 2015). Within this, the disclosure of corporate supply chain information among stakeholders (i.e. factory locations, workforce, supplier audit reports) increases stakeholder understanding of the GVC and how sustainability issues are addressed, allowing stakeholders to participate (Stauffer, 2017). Supply chain transparency also enables the buyers to know where and how products are made, making highly profitable brands more accountable while also allowing ethical consumption and investment habits to contribute to improving sustainability (Wittstruck and Teuteberg, 2012; Evermann, 2014). Furthermore, this article echoes a large proportion of civil society literature which advocates for the incorporation of suppliers, workers and local labour institutions into corporate supply chain governance, forming part of a multi-level and collective approach for corporate compliance to sustainability standards (Overeem, 2009; Martin-Ortega, 2018). Within this, workers throughout the global electronics value chain should be educated to monitor their working conditions and work with local CSOs to ensure compliance with sustainability standards (Raj-Reichert, 2011; Martin-Ortega, 2018). By involving stakeholders in this way, it is the opinion of this article that MNCs can overcome many of the limitations of market governance and more effectively implement sustainability management throughout the GVC.

8. Conclusions

By extracting and condensing arguments from 80 empirical articles, this research analyses the overall effectiveness of different approaches to sustainability governance across the electronics GVC. In summary, supply chain transparency and building trust between actors at different scales in the GVC increase cooperation within governance across the electronics GVC. Thus, enabling actors to more effectively identify and develop solutions for sustainability risks (Wittstruck and Teuteberg, 2012; Martin-Ortega, 2018). By providing empirical evidence that corporate transparency and interactive governance lead to more effective sustainability governance, this literature review will serve to inform industry and state policymakers regarding the importance of developing and enforcing rigorous sustainability standards at national and international scales. Furthermore, electronics brands can use these results to develop corporate policies for supply chain sustainability, while those at the forefront of sustainability governance should encourage those lagging behind. Within this, CSOs have a vital role in supporting as well as validating corporate sustainability efforts, while using these research findings and media channels to leverage change among companies which fail to meet sustainability standards.

Yet, this should not assume a normative position that more interactive approaches will facilitate more effective governance. The scope of the electronics value chain is vast and a challenge for any system of governance. Multi-stakeholder approaches can spread responsibilities between actors at various levels of governance but also create cumbersome networks of actors, increasing transaction costs and reaction times. For example, despite multi-stakeholder involvement in EPR, this has failed to establish a global solution for e-waste and prevent leakages of e-waste into informal markets. Instead, the authors have the view that the scientific community should critically assess how interactions between multiple actors can facilitate opportunities for (formal and informal) institutional change, resulting in progressive policy addressing electronics sustainability. Furthermore, despite the optimism surrounding interactive governance, there are also barriers to combining top-down governance with intricate local hierarchical arrangements and norms. For example, while all parties may recognise the benefit of information sharing and participation, companies and government authorities are often resistant to changing operating procedures and being inclusive due to a range of cultural, political, economic and logical reasons. Therefore, the development of long-term institutional commitments for interactive management is a complex and slow process. Finally, the authors stress the need for more formal testing of these approaches and a lack of models or best practices in the electronics sector.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.122952.

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