Sustainability and Sustainable Development Strategies in the U.K. Plastic Electronics Industry

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ABSTRACT

The growing plastic electronics industry constitutes an important arena for addressing sustainability challenges. This study integrates literature related to eco-innovations and ecocentric business strategies to investigate its ability to adopt a sustainable development strategy based on ecological sustainability. An exploratory qualitative study in the U.K. market reveals the need for both technological-push and market-pull factors to guide technological development. Awareness of sustainable development and the potential to support it are high, but actors in this sector do not prioritize these concerns. Efforts to increase commitment to sustainable development must address three, distinctive groups: innovative developers, supplier/manufacturers, and industry facilitators. Articulating the importance of sustainable development might create incentives and generate market pull. The industry also has potential to support sustainable development, which then can support industry development. This article thus offers theoretical insights for ecocentric eco-innovations, ecocentric business strategy, and ecocentric visionary leadership, along with managerial, industry, and policy implications.

Keywords: Ecocentric industry strategy; eco-innovations; plastic electronics; sustainable development; sustainability vision.

INTRODUCTION

Sustainability and sustainable development are foremost human concerns, largely due to the imbalance between evolving human needs and the availability of natural resources to support them (George, Schillebeeckx & Lit Liak, 2015; Provasnek, Sentic, & Schmid, 2017). As human populations grow, their consumption of natural resources increases, producing environmental pollution, waste, and natural systems degradation (Borland, Ambrosini, Lindgreen, & Vanhamme, 2016; Howard-Grenville, Buckle, Hoskins, & George 2014; Kelley & Nahser, 2014; Panwar, Hansen & Kozak, 2014; Poisson de Haro & Bitektine, 2015). In this setting, technology can have double-edged effects: It can initiate goods and services that facilitate improvements to living conditions, but it also accelerates the destruction of natural environments at an unsustainable pace (Costantini, Crespi, Martini, & Pennacchio, 2015; Horbach, Rammer, & Rennings, 2012; Uyarra, Shapira, & Harding, 2016).

The concepts of eco-innovations (Ghisetti & Pontoni, 2015; Horbach, 2008; Marin, Marzucchi, & Zoboli, 2015; Uyarra et al., 2016) and sustainability innovations (Staub, Kaynak, & Gok, 2016) reflect this view. Eco-innovations consist of new or modified processes, techniques, systems, and products that have been designed explicitly to avoid or reduce environmental damage (Costantini et al., 2015) and climate change (Uyarra et al., 2016). Research that seeks to identify catalysts of eco-innovations uses both theoretical and empirical models and suggests that both technology-push and demand-pull forces shape the rates of introduction and diffusion of new environmental technologies, along with public policies (Chassagnon & Haned, 2015; Del Rio, 2009; Horbach, 2008). Costantini et al. (2015) distinguish technology-push (e.g., funded exploration) from demand-pull (e.g., tax exemption) forces and propose that they correlate with the stage of maturity. For example, less mature eco-innovations, such as plastic electronics, require both technology-push and demand-pull forces to achieve market success; price-based forces (e.g., feed-in tariffs, tax exemptions) also exert a greater innovation inducement effect than do quantity-based tools (e.g., quotas, targets). Other research classifies various drivers of eco-innovations as positive or negative, including cost savings, regulations, organizational change, and customer benefits (Chassagnon & Haned, 2015; Ghisetti & Pontoni, 2015; Horbach, 2008; Kesidou & Demirel, 2012; Marin et al., 2015; Polzin, von Flotow, & Klerkx, 2016; Rennings, 2000). For Horbach et al. (2012), eco-innovation determinants depend on the environmental impact and thus vary, depending on whether the goal is to encourage firms to reduce pollution or else increase product recyclability. Amankwah-Amoah and Sarpong (2016) focus on the need for government financial support for scale-up and capacity-building eco-innovations. According to Chassagnon and Haned (2015), environmental regulations can induce market competitiveness, by supporting differentiation and first-mover advantages.

Yet eco-innovations literature remains firmly rooted in an anthropocentric domain, relying on humans' faith in science and technology and limited government intervention to encourage *reduction, recycling,* or *regulation.* As an alternative, Borland et al. (2016) suggest distinguishing between a *transitional* strategy that highlights the five Rs (reduce, reuse, repair, recycle, and regulate) according to an anthropocentric view and a *transformational* strategy that consists of five different Rs (rethink, reinvent, redesign, redirect, and recover [integrating closed loops and zero waste]) in an ecocentric domain. For eco-innovations to be truly successful, according to technological, market, and ecological sustainability perspectives, an ecocentric transformational strategy may be necessary, because it can enable firms and governments to address the *elimination* of negative environmental impacts and move beyond a reduction-and-recycling approach (which does not achieve sustainability). Eco-innovations then can enhance firms' strategic activity, human society, and the natural environment.

In addition to this theoretical insight, this article aims to identify ways to achieve an ecocentric transformational strategy for eco-innovations, using a nascent innovative technology industry as the context. The U.K. plastic electronics industry currently displays little concern for sustainability, sustainable development, or eco-innovations, but key stakeholders must start thinking about these issues (demand-pull force) for the future of their industry. In interviews with these stakeholders, in which we obtain insights from a sample that represents approximately 85% of the supply side of the industry, we ask: How can the U.K. plastic electronics industry support sustainable development and sustainability? The deliberately simple interview questions avoid alienating industry participants and encourage sustainability thinking. The resulting analysis indicates strong industry potential, both technically and practically, to apply sustainability and sustainable development principles. As a contribution to eco-innovations literature, we show that moving beyond a traditional, anthropocentric, eco-innovation approach and toward an ecocentric, eco-innovation one requires that the ecocentric, transformational business strategy gets adopted and enhanced by *ecocentric visionary leadership*. Our findings thus build on work by Chassagnon and Haned (2015) that identifies the importance of innovative leaders for implementing eco-innovations, with a more nuanced understanding of innovation leadership.

For managers and policy makers, our research in turn recommends supporting and encouraging an ecocentric, rather than an anthropocentric, approach to eco-innovations, then making plastic electronic industry stakeholders more aware of this option. Education, advice, and capacity-building support is required (Amankwah-Amoah & Sarpong, 2016; Bernal-Conesa, de Nieves Nieto & Briones-Penalver, 2017; Uyarra et al., 2016). For example, the circular economy and cradle-to-cradle strategies should be made available to and adopted by plastic electronic industry players (Borland et al., 2016; George et al., 2015).

PLASTIC ELECTRONICS

The plastic electronics industry represents a new, fast-changing sector that, due to its newness and potential flexibility, might develop along sustainable lines and do things differently than incumbent, highly polluting, electronic industries currently do. The rapidly growing problem of electronic waste demands urgent, detailed investigation. This industry integrates electronic material into flexible surfaces, such as paper, foil, fabric, or plastic. Technological advances allow the inclusion of electronic material at low temperatures, such that flexible surfaces can incorporate electronic components, including conductors, insulators, and semiconductors. The resulting low cost, high functionality products and smart materials offer the potential to change the way people live, with applications ranging from smart packaging, displays, and signage to lightweight, flexible power sources, to lighting panels of any size or shape, to low cost medical diagnostic devices and smart bandages that dispense topical treatments. Research into sustainability opportunities is on-going, focused on recyclability and reusability, the bio-degradability of plastic substrates, and graphene printable circuits. Bio-degradable flexible substrates generally are not a problem for sustainability, consistent with an ecocentric, transformational business strategy (Borland et al., 2016). The bio-degradability of graphene, a carbon-based compound, is more problematic. Continued research thus seeks ways to metabolize grapheme, to prevent it from becoming an environmental hazard, if and when production gets scaled up (Kurapati, 2015).

Because the global market for plastic electronics is likely to reach $45 billion by 2020 (Logystyx UK, 2012), the pace of technological innovation is great, and companies should recognize how plastic electronics might change their business models and create new sources of customer value (King, 2009). Many developments have resulted from technological pushes, but an emerging consensus indicates that the industry has reached a stage at which it requires input and influence from end users, to accelerate its development through market pulls and the requirements of specific market applications (King, 2009). As Rogers (2012) confirms, exciting concepts have yet to be translated into commercially available products, so the opportunity to shape technological developments still exists.

Plastic electronics circuitry also varies in its complexity. To achieve complex functionality (e.g., large displays), the uniformity and repeatability standards for fabricating transistors must be better than 95%. This level of performance is relatively easy to achieve on rigid substrates, but it creates complex scientific and technical challenges for flexible substrates such as plastic. Therefore, innovative manufacturing processes continue to seek options for delivering the required performance capabilities.

Government Support

Governments worldwide recognize the significant industrial and strategic importance of plastic electronics, prompting them to seek national capabilities in this domain. Because production currently is small in scale (and experimental) and largely reliant on carbon-based molecules rather than extractive industries, most national governments want to develop domestic manufacturing capabilities. In this nascent industry, the markets, brands, supply chains, and value chains are not well developed and change constantly. For example, the plastic electronics capability of the United Kingdom started with research conducted at Cambridge in 1984, after which the U.K. Department of Trade and Industry and then the Department of Business, Innovation and Skills (2009) supported this nascent field with a range of funding programs. After identifying plastic electronics as a key area of development, it launched the U.K. Plastic Electronics Strategy in 2009, together with an investment to promote industry growth. Government support comes from Innovate UK (previously the Technology Strategy Board) and the Engineering and Physical Science Research Council; a supportive infrastructure also exists. Five regional centers of excellence offer open access facilities to accelerate technical development and prototyping; multiple knowledge transfer networks help promote collaboration; and a Plastic Electronics Leadership Group, comprising commercial and public interests, has the mission to promote industry development. The Technology Strategy Board's (2012) high value manufacturing strategy also seeks to address market needs in key areas to help U.K. companies succeed in global markets. This strategy informs both public policies and investment programs, according to five strategic themes (Table 1). The plastic electronics industry can contribute to all these themes, so it is highly relevant to and should benefit from this high value manufacturing strategy. As we show, applying sustainability and sustainable development as part of a strategic approach to plastic electronics makes each theme even more viable.

(Insert table 1 here)

Current State of the Industry

Rogers (2012) asserts that most plastic electronics concepts have not yet become available as commercial products because of insufficient supply chains. Although Samsung has committed billions of Euros to scale up its plastic electronics supply chain and incorporate organic, light-emitting diodes into the display screen of its Galaxy smartphones, few other companies have been willing to commit similar resources.

Furthermore, plastic electronics are unlikely to replace conventional electronics; instead, they can supplement and complement them (Logystyx UK, 2012). Their more advanced capabilities also could result in novel product concepts that would not be possible with conventional electronics (e.g., electronics fabricated onto textiles). Thus the potential is great, but so are the scientific and technical challenges, which span chemistry, physics, electronics, systems integration, and process engineering. The applications of plastic electronics currently are more prevalent to increase efficiency and performance, rather than offer novel functionalities. This early stage of development, along with clear needs for an industry strategy and market pull factors to guide development, suggests an opportunity for the industry to support both sustainability and sustainable development through the design of its products, services, and places, from the very outset (Brindley & Oxborrow, 2014).

CONCEPTUAL DEVELOPMENT

As a product, plastic electronics consist of two main components: a flexible substrate and electronic circuitry. From a sustainability perspective, this dual state presents a challenge, because the two elements conflict in their potential to be reused, recycled, or biodegraded, such that they combine into “monstrous hybrids” (McDonough & Braungart 2013). The flexible substrate might be made of materials that are fully compostable, such as corn starch plastic, which ultimately will biodegrade. The circuitry uses grapheme, a thin, strong material with excellent conductive properties that forms from carbon atoms and is more conductive than copper. When the substrate and graphene combine, they establish strong semi-conductors. However, graphene is not currently biodegradable. Although research is underway to apply human enzymes to metabolize graphene, it has yet to achieve the intended outcomes. Waste is already a significant problem for electronics, so finding solutions for plastic electronics is paramount to prevent adding to environmental burdens (Kurapati, 2015).

In particular, the volume of global electronic waste (e-waste) has been rising steadily, expected to reach 50 million tons in 2018, up from 41 million tons earlier in the decade (United Nations). This trend reflects the rapid pace of product replacement, due to shorter product lifecycles for consumer electronics, which rarely are designed for reparability, recycling, or biodegradability. Yet managing e-waste is not a business imperative, despite its high social and environmental costs. If e-waste recycling and biodegradability are to become core business objectives, they need to deliver business value by reducing costs or generating new revenue streams, or both. Such outcomes would be difficult to achieve with a conventional, linear business model, in which resource extraction precedes manufacturing, which leads to consumption and disposal. No process exists for the reuse or recycling of disposed products and materials, because waste is excluded from the value chain in this business model.

Some attitudes are changing though, reflecting a growing consensus that the linear model simply is unsustainable. Research by Accenture indicates that population growth, resource supply disruptions, volatile material prices, and the scarcity of natural resources will result in significant financial losses in the next two decades for companies and countries whose growth is tied to the use of scarce natural resources. In response, one approach may be to transition from a linear to a closed-loop model, in which waste becomes the primary input for new product creation. By reducing resource extraction and maximizing the reuse and recycling of materials in the production process, this model would increase demand for recycled resources, and prices may follow, which would help reverse financial losses and potentially create significant financial opportunities.

Recycling and reuse thus are only part of the picture, tied to a transitional strategy for sustainable development (Borland et al., 2016). Biodegradability (composting) and closed-loop industrial cycles (reusing industrial materials indefinitely) instead reflect a transformational strategy. The former is linked to an anthropocentric view; the latter implies an ecocentric view (Borland et al., 2016). Figure 1 outlines this conceptual framework, which also goes a step further in an attempt to enhance eco-innovations to create regenerative and restorative opportunities for sustainability.

(Insert Figure 1 here)

In the new, developing plastic electronics industry in particular, opportunities already exist for plastic electronics to be made of bio-degradable flexible substrates that are fully compostable and for graphene-printed circuits to be metabolized using human enzymes (or reused indefinitely). Then they would become non-toxic to species and the environment, consistent with both the 5Rs approach to ecocentric transformational strategy (rethink, reinvent, redesign, redirect and recover; Borland et al., 2016) and the concept of ecocentric eco-innovations (Chassagnon and Haned, 2015).

RESEARCH PROPOSITIONS

Hart (2012) argues that firms are engines of change for sustainability, supported by governments, and that their consumer and supply chain reach enables them to address sustainability challenges, such as climate change and resource shortages. They also possess the required technological and financial clout to implement change. Borland et al. (2016), Gao and Bansal (2013), and Hart (1997, 2007, 2012) also suggest that to drive change, companies require a sustainability vision that acknowledges how sustainable products and services might evolve over time and what competencies they will need.

Plastic Electronics, Sustainability, and Sustainable Development

We rely on the guiding research question we posed in the introduction: How can the U.K. plastic electronics industry support sustainable development and sustainability? To define this potential, we start by investigating how these terms are understood within the industry, particularly by key stakeholders, which might have distinct conceptions. For example, some aspects of sustainable development may appear more relevant to different stakeholder groups because of their varied roles and unique understanding of plastic electronics manufacturing. These views in turn may influence the extent to which the industry's potential to support sustainable development can be realized. Accordingly, we turn to King's (2009) identification of three key stakeholder groups: *innovative developers*, or the early-stage technology innovators who own the foundational intellectual property for a new technology (e.g., centers of excellence); *suppliers/manufacturers*, which make the related items and finished components and which, in the nascent plastic electronics industry, tend to be low volume, bespoke manufacturers; and *customers*, including companies that buy the finished plastic electronics components and assemble them with other components to create a finished product for retail sale. We also add *industry facilitators* that enable the broad development of the industry, such as knowledge transfer networks or plastic electronics specialist media.

These industry facilitators should have a broad understanding of the development of the whole industry, its strategy, its value chain, and its vision for the future. From this foundation, we develop three propositions.

First, we consider whether sustainable development is regarded positively (e.g., spurs creativity) or negatively (e.g., hinders progress). Sustainability often is depicted as a burden on society rather than as a means to progress or improve the quality of life (Borland & Lindgreen, 2013; Hart, 1997, 2007, 2012). Accordingly, we investigate whether various stakeholders perceive sustainable development as supportive of or antithetical to industry, as well as whether they consider sustainable development in terms of its ability to support ecology, prosperity, and well-being (Gabler, Panagopoulos, Vlachos & Rapp, 2017; Gao & Bansal, 2013; Testa, Gusmerottia, Corsini, & Passetti, 2016).

Proposition 1: *Stakeholders in the U.K. plastic electronics industry express different levels of awareness of sustainable development.*

Second, moving beyond initial awareness, we consider the industry's potential to support sustainable development. This potential is particularly relevant given the broad definition of sustainable development as an innovative, entrepreneurial process based on sound ecological science, for which commerce is an engine of positive change (Gao & Bansal, 2013; Hart, 1997, 2012; Shrivastava, 1995; Victor, 2013).

Proposition 2: *Stakeholders in the U.K. plastic electronics industry have different conceptions of the potential of plastic electronics for sustainable development.*

Third, it is important to investigate whether stakeholders believe that end users are interested in sustainable development, as might be manifest in the range of needs they express. This proposition is of particular interest, given the need for market-pull forces to guide technical development (Borland & Lindgreen, 2013; Hult, 2011; Varey, 2010).

Proposition 3: *Stakeholders in the U.K. plastic electronics industry have different conceptions of end users' awareness of the potential of plastic electronics for sustainable development.*

METHODOLOGY

We used an embedded exploratory case study design with a replication logic. Exploratory case studies focus on how and why questions, "to develop pertinent hypotheses and propositions for further inquiry" (Yin, 2009: 9), and a replication logic offers enhanced validity by providing either similar results (literal replication) or contradictory ones for evident reasons (theoretical replication). This design is appropriate for two main reasons. First, plastic electronics is a contemporary phenomenon, and its development is occurring within a wider, global manufacturing context. Its clear relation to the Technology Strategy Board's (2012) strategic themes, as well as the frequent integration of plastic electronics into products that also feature conventional, silicon-based electronics, suggest that it would be difficult to draw clear boundaries between the plastic electronics industry and its wider manufacturing context. As Yin (2009) defines it, a case study is effective for investigating a contemporary phenomenon in its real-world context when the boundaries between the phenomenon and the context are not clear. Second, our research question is exploratory. To investigate similarities and differences across different stakeholder groups, a multiple case study design is appropriate, in which each stakeholder group constitutes a case, and individual participants are embedded units of analysis within each case (Stake, 2013).

Interviewees

The study participants represented the key stakeholder groups and fit our replication design. We identified two participants each from the innovative developer, supplier/manufacturer, and industry facilitator groups (King, 2009; Scholz & Tietje, 2002), which enabled a literal replication test. Another respondent from each of the innovative developer and supplier/manufacturer groups represented the perspective of actors who favored more conventional, silicon-based electronics. Thus we could engage in theoretical replication, in that we expect contrasting results from these skeptical participants. The names of the participants and their organizations are withheld, to preserve anonymity—a necessary provision for ensuring both recruitment efforts and response quality (Stake, 2013). These goals are particularly relevant for members of the U.K. plastic electronics industry, which features high levels of mutual awareness due to the supportive infrastructure. We provide broad descriptions of the organizations and assigned case study groups in Figure 2.

(Insert Figure 2 here)

Inquiry

Participants received an "Introduction to the Interview" that identified the investigators, described the study purpose, and stated that all data would be anonymous and participants' confidentiality would be carefully safeguarded. A "Frequently Asked Questions" sheet provided descriptions of the case study design and sustainable development. To investigate our three propositions, we transposed them into case study questions:

1. **What do you understand by the term sustainable development?** We needed respondents to consider the sustainability potential of plastic electronics in reference to a broad definition of sustainable development; otherwise, conceptions of its potential would be bounded by the level of awareness of sustainable development. If participants did not demonstrate sufficient knowledge of sustainable development in their response to question 1, we introduced it to them prior to asking question 2.
2. **Given these elements of sustainable development (e.g., commerce as engine for innovation and change, entrepreneurial focus, sustained prosperity, personal well-being underpinned by a healthy ecology), what do you believe is the potential of plastic electronics to support sustainable development?** With this

question, we sought to ascertain whether participants could link the broad definition of sustainable development to their industry and apply sustainable development to it.

3. **Do you feel that end users (B2B) recognize or are aware of the potential of plastic electronics for sustainable development?** With this question, we explored whether stakeholders believe end users demonstrate concern for sustainable development and whether it was manifest in the range of requirements they had. This question is of particular interest for determining the market pull to guide technical development.

Procedure

Participants first reviewed the introductory sheet, before we arranged interviews. The interviews were conducted in person, with one exception (participant 6 was interviewed via telephone), and the researcher took notes directly onto the question sheets. At the end of each interview, participants were debriefed and offered the frequently asked questions sheet.

We analyzed the collected responses by proposition and by group. In accordance with our multiple case study design, each group represented a case (Stake, 2013; Yin, 2014). We did not conduct any analyses at the individual participant level, because individuals are embedded within each case (Figure 2). The preliminary collation of responses by proposition revealed several themes that form the basis of our results.

FINDINGS AND ANALYSIS

To address Proposition 1, we used the responses to question 1. The prepared, broad definition of sustainable development was introduced prior to question 2, so our investigation of Propositions 2 and 3 was not bounded by the participants' initial awareness of the term. For Propositions 2 and 3, we used the responses to any of the three questions, thus approaching the case study interview as a guided conversation. Table 2 provides a summary of the results for each proposition by theme and the cases in which these themes were identified.

(Insert table 2 here)

Analysis by Proposition

By considering the responses to question 1, designed to assess respondents' initial awareness of sustainable development, we determined that each case offered some definition. However, only the innovative developer and industry facilitator mentioned elements that reflected the broad definition, including sustained prosperity and personal well-being, underpinned by sound ecology. The participants, with the exception of an industry facilitator (7), made some reference to ecology in all their responses, whereas prosperity and well-being elements appeared in only two responses, with little consistency across their definitions:

> "Development of business, peoples' livelihoods, continued without exhausting resources, energy, to continue forever." [Innovative Developer 2]
>
> "Develop new industry to sustain in UK." [Industry Facilitator 8]

The supplier/manufacturer instead indicated greater concerns for material recycling, perhaps reflecting this group's concern with technical development and awareness of sources of materials. This case also featured descriptions of sustainable development as a positive opportunity and was the only one to suggest that it was not a priority (for industry). Supplier/manufacturers tend to have the closest relationships with end users, so the extent of market pull is an important consideration. Although regarding sustainable development as a positive opportunity is consistent with an awareness of how to operate in a market, the lack of priority assigned to sustainable development suggests very little existing market pull. In contrast, the innovative developer case expressed a distinctive wariness about rushing into a technical solution for sustainable development. These respondents emphasized the need for a change in mindset, by both consumers and industry:

> "Very complex area—for true sustainable development, it's not about changing technology but about changing the consumer mindset, e.g. "throwaway" culture.... Industry is based on disposability/novelty." [Innovative Developer 3]

This perspective may appear surprising, considering innovative developers' vested interest in technical solutions, but it implies a mature outlook on both the potential and the limitations of any technical development to address an issue as broad as sustainable development.

In relation to Proposition 2, all cases could suggest various applications of plastic electronics to support sustainable development, but not all potential applications included an ecology element. For example, participants cited

> "better design options." [Innovative Developer 1]
>
> "smart objects, ... internet of things." [Innovative Developer 2]
>
> "[to support a] communication-driven society." [Industry Facilitator 7]

The prepared, broad definition of sustainable development, underpinned by ecology, thus may need further development, to make it consistent with the innovative potential of plastic electronics and the overall emphasis on commerce as an engine for change. The supplier/manufacturer case again demonstrated its unique market sensibilities, by referring to the potential for sustainable development as a source of differentiation and competitive advantage. These respondents also indicated their interest in technical development, with comments about recyclability and toxicity. Finally, the industry facilitator was distinctive, because it referred explicitly to the need for strategic, supported development:

> "For plastic electronics a coherent strategy and roadmap for the full value chain to exist in the long term, developers supported—public and private included—scale up and deliver to market." [Industry Facilitator 7]

This view is consistent with industry facilitators' industry-wide perspective and awareness of the need to gain support at various points along the plastic electronics value chain.

In our investigation of Proposition 3, all cases asserted that end users exhibited low awareness and that more needed to be done to raise it. The industry facilitator case suggested specific funding support to raise awareness, consistent with its industry-wide perspective:

"Make benefits really apparent—produce demonstrators—need funding, still need to bridge the gap between R&D and end users." [Industry Facilitator 8]

In addition to statements related specifically to each proposition, we noted some more general, insightful responses about the industry and its development. We group these statements with our Proposition 3 analysis, because they mostly emerged during discussions of end users. For example, each case emphasized the need to deliver real benefits and specific applications to end users, consistent with the suggestion that plastic electronics complement, rather than replace, existing technology. They also mentioned the need to consider competing technology, particularly in current market conditions:

> "Regarding OPV [organic photovoltaics], China has currently swamped the market with cheap silicon. This has made OPV financially unviable in the short term.... Can use non-plastic electronics, e.g. not OLED [organic light emitting diode] or OPV. End-user benefit identical—plastic electronics less efficient. Plastic electronics lighter in weight, less likely to break.... Growing awareness—but competing technologies—silicon becoming thinner, now flexible.... LED chips can now be made 100 microns thick—functionality of an OLED?" [Innovative Developer 2]

However, respondents in the innovative developer case were the only ones to mention raising awareness of not just the potential but also the limitations of current plastic electronics technology. They specifically wondered if the industry should pursue niche applications:

> "Need to look at niches, not just search for the 'killer app.'" [Innovative Developer 1]

In parallel, the industry facilitator case featured a suggestion that the adoption of plastic electronics by end users would be piecemeal, rather than through a "killer application":

> "End users as integrated groups—packages, will develop by seeing successes of others, examples—new and promising area, case by case awareness as converts use applications." [Industry Facilitator 7]

This emphasis on real benefits for niche applications suggests that plastic electronics must compete with other technologies on the basis of price and performance, rather than just novel functionalities. Therefore, focusing on the benefits of specific applications, identified by each case, is of central importance. Finally, the industry facilitator case implied that consumers may not be interested in whether their product contains plastic electronics:

> “Not necessary for consumer to consider, e.g. smartphones—all about display, look, performance. Consumers need to feel benefits.” [Industry Facilitator 7]

Yet the supplier/manufacturer case suggested that the development of international standards may help accelerate technical developments, by focusing efforts and encouraging the involvement of subsidiary industries (e.g., tool or equipment manufacturers).

Analysis by Case

The distinctiveness of the three cases comes even more clearly to the fore when we consider their responses across propositions. The innovative developer case, though aware of the potential of plastic electronics, seemed to be managing expectations, as was evident in references to the need to raise awareness of technology limitations and consider niche applications, as well as a more general wariness about pursuing purely technical solutions for sustainable development. One innovative developer respondent favored a competing technology (i.e., plastic electronics skeptic, Innovative Developer 3). In line with theoretical replication concepts, we might expect a sharp contrast between this skeptic and the rest of the group, yet each of the themes raised by the skeptic matched the responses of the other participants in this case: wariness about technological solutions and the potential of plastic electronics to support sustainable development; the limitations of plastic electronics; and the need to consider both niche applications and competing technologies. Thus, we find evidence of literal replication in these consistent responses. The failure to demonstrate theoretical replication in turn suggests a greater degree of commonality in the innovative developer case than we expected, which persisted whether the participant was skeptical of plastic electronics or not. Perhaps the plastic electronics skeptic was not particularly skeptical; alternatively, the other participants might have their own reservations about the potential of plastic electronics to support sustainable development. For example, Innovative Developer 3 worried:

> "Plastic electronics is 50 years behind silicon development…. Plastic electronics as providing a solution to a number of niche problems—not a replacement for existing manufacturing technology—e.g., large area wall lighting, lightweight can be achieved in many ways."

The representatives in this case thus express a balanced view of plastic electronics, acknowledging its potential but also expressing awareness of its limitations. Ultimately, the literal replication and the distinctiveness of some of the issues raised offer support for the external validity of innovative developers as a distinct group.

The supplier/manufacturer case also was distinctive in expressing strong market awareness, such as recognizing sustainable development as a positive opportunity and potential source of differentiation or competitive advantage. We anticipated this strong market awareness, considering the group's proximity to end users in the overall value chain. Market awareness is fundamental to the supplier/manufacturers' continued existence in a developing market. This case also contained a participant who favored a competing technology (Supplier/Manufacturer 6). Although consistent with the other supplier/manufacturer participants in expressing a distinctive concern for materials and recyclability, this skeptic asserted that greater recyclability was possible with new developments in silicon-based electronics. This participant was the only one to suggest a competing technology, consistent with a skeptical view of plastic electronics:

> "Plastic electronics trying to do too much too soon." [Supplier/Manufacturer 6]

Therefore, we find evidence of literal replication with regard to distinctive concerns raised by this case, such as the concern for materials and recyclability. Theoretical replication instead emerged for the characteristics of plastic electronics that the skeptic viewed negatively, whereas the others saw them in a positive light. The literal and theoretical replications support the external validity of the supplier/manufacturer as a distinct group.

Finally, the industry facilitator case was distinctive in its concern for supported, strategic development across the entire value chain. For example,

> "For the plastic electronics industry a coherent strategy and roadmap for the full value chain to exist in the long term, developers supported – public and private included – scale up and deliver to market." [Industry Facilitator 7]
>
> "Make benefits really apparent – produce demonstrators – need funding, still need to bridge the gap between R&D and end users." [Industry Facilitator 8]

The industry facilitator case did not contain a skeptic. However, we observed literal replication regarding the consistency and distinctiveness of the concern about the development of the whole industry. Thus, we can confirm the external validity of this group.

DISCUSSION

Potential of Plastic Electronics to Support Sustainable Development

Our case analyses demonstrate a high level of awareness of the importance of sustainable development among plastic electronics industry actors. Yet they also indicate room for more in-depth understanding, application, and opportunities involving the broad definition of sustainable development (healthy ecology, personal well-being, sustained prosperity; Borland et al., 2016; Gao & Bansal, 2013; Hahn, Pinske, Preuss, & Figge, 2014; Ramirez, Gonzalez, & Moreira, 2014; Victor, 2013). When we introduced this definition, prior to posing question 2, all participants were able to identify examples to demonstrate the potential of the plastic electronics industry to support sustainable development. Prior literature also suggests the potential benefits of sustainable development in this industry, such as bio-degradability, recyclability, elimination of toxic waste, and improved medical applications. It is thus important to verify the salience of each element for each stakeholder group. Despite the awareness demonstrated by each case, we find little evidence of existing market-pull forces for sustainable development, as described by the supplier/manufacturer case; participants believed that awareness among end users was low and needed to be increased.

The distinctiveness of each case supports the identification of unique groups. The relevance of sustainable development must be separately and clearly articulated to each stakeholder group in the plastic electronics value chain (Ramirez et al., 2014; Tatoglu, Bayraktar, Sahadev, Demirbag, & Glaister, 2014; Vallaster & Lindgreen, 2013). For example, the supplier/manufacturer group raised more ecological concerns, such as recyclability and reducing material toxicity, but the broad definition of sustainable development was more likely to engage innovative developers, industry facilitators, and end users.

Because the broad definition of sustainable development is non-prescriptive, it may create implementation difficulties (Ramirez et al., 2014). As Porritt (2007) notes, labor costs and physical environment quality likely are pertinent issues. Increasing awareness will not necessarily increase the perceived importance, value, or understanding of how to adopt sustainable development strategies, unless stakeholders learn how to engage in positive, sustainable behaviors (Borland et al., 2016; Poisson de Haro & Bitektine, 2015; Stam, Lord, van Knippenberg, & Wisse, 2014; Van der Werff, Steg, & Keizer, 2013) and thus enjoy positive, sustainable business benefits (Borland et al., 2016; Hahn & Figge, 2011; Hart, 1997).

Capacity-building support programs, involving the infrastructure of the plastic electronics industry and the U.K. government's high volume manufacturing strategy, are consistent with the goal to achieve sustainable development. Government actions matter, because national institutions influence firms' social and environmental behaviors (Ioannou &

Serafeim, 2012). (For a review of scaling-up and capacity-building literature, see Amankwah-Amoah & Sarpong, 2016.) The United Nations' Rio +20 actions establish both goals for sustainable development and a financing strategy; its "Sustainable Energy for All" initiative suggests the potential mobilization of further sources of support. However, without a clear articulation, sustainable development may suffer limited success in an industry driven by technical know-how rather than market demand, such that the potential of plastic electronics to support sustainable development may fail to be realized.

Potential of Sustainable Development to Support Plastic Electronics

The development and implementation of appropriate drivers and incentives, supported by strategic industry development and appropriate funding (industry facilitator case), may have reciprocal effects. We have focused on how plastic electronics can support sustainable development, but sustainable development may support plastic electronics too. In the supplier/manufacturer case, we find evidence that sustainable development offers a positive opportunity and potential basis for differentiation and competitive advantage. Further scientific and technical development is required to commercialize novel applications of plastic electronics, in competition with conventional technologies. Yet we can already find examples of plastic electronics outcompeting conventional technologies, with more efficient production processes and ecologically sound production materials, such as bio-degradable flexible substrates, metabolizable graphene printed circuits, and surfactant-free inks. If these characteristics are valued by the market, they can create sustainability-led competitive advantages (Borland et al., 2016; Chassagnon & Haned, 2015; Gupta, Czinkota, & Melewar, 2013; Melewar, Gupta, & Czinkota, 2013; Ramirez, 2013; Stead & Stead, 2000, 2014) to support the development of a sustainable plastic electronics industry. In turn, if plastic electronics firms demonstrate sustainable differentiation and competitive advantages, they might gain a viable position to develop a corporate or industry sustainability vision and roadmap (Borland et al., 2016; Chassagnon & Haned, 2015; Hart, 1997) that will influence strategic thinking. This sustainability vision then could guide the future development of the U.K. plastic electronics industry by supporting strategic, ecocentric, transformational change (Borland et al., 2016), such that it achieves eco-effectiveness (McDonough & Braungart, 2002, 2013; Rossi, Charon, Wing, & Ewell, 2006) and harnesses the inherent ability of ecosystems to self-regulate and self-perpetuate.

To be ecocentric and eco-effective, industrial systems must be designed cradle-to-cradle, with closed loops, such that energy and resources get transformed into products whose wastes are absorbed and reused (Dutt & King, 2014). Eco-effectiveness provides multiple commercial benefits: the elimination of the social, economic, and environmental costs of extracting and purchasing raw materials and disposing of waste materials; positive effects on the organization's image and reputation; and the opportunity to introduce a business model for renting, rather than purchasing, products, to support the return of nutrients to biological and technical cycles (Borland et al., 2016; McDonough & Braungart, 2013). Such developments might be augmented with a closed-loop, ecocentric, servitization business model (Baines, Lightfoot, Peppard, Johnson, Tiwari, & Shehab, 2009; Neely, 2008; Ulaga & Loveland, 2014), in which customers receive support from a range of complementary offerings that generate additional revenue and enter a sort of soft lock-in that does not increase environmental impacts.

The "ecopreneur" company Eight 19 (2012; see also George et al., 2015) offers a prime example of niche creation for an ecocentric servitization business model based on sustainable development principles (underpinned by ecological sustainability). It developed solar energy technology for a very large niche: billions of global, rural poor who could generate strong market pull while supporting the development of a strong sustainability vision (Amankwah-Amoah & Sarpong, 2016). The base of the pyramid may particularly favor bold, disruptive technology (Hart, 2007; Kistruck, Beamish, Qureshi, & Sutter, 2013; London, 2009; London, Anupindi, & Sheth, 2010), because it has fewer sunk capital investments (Chassagnon & Haned, 2015; Downes & Nunes, 2013) and prompts fewer protectionist countermeasures. This notion resonates with the claim from our innovative developer case that China has been flooding the market with cheap silicon to undermine the organic photovoltaic market in developing countries. An innovative ecocentric servitization leasing technology business model developed by Eight 19 represents a key feature of its sustainability vision and leadership, and it enables valuable industrial materials to remain in the industrial system, in closed-loop cycles, without generating waste.

The convergence of multiple push and pull drivers of sustainable development encourage sustainable innovation and technical development and reiterate that the plastic electronics industry must develop according to a framework that is consistent with sustainable development and sustainability (Amankwah-Amoah & Sarpong, 2016). The current research reveals the need for this industry to recognize this requirement and capitalize on the competitive advantage and market pull that sustainable development and a sustainability vision can provide, by adopting an ecocentric, transformational strategy (Borland et al., 2016) and an ecocentric servitization model to support its development. These market implications likely apply not only in the United Kingdom but also in other countries developing plastic electronics industries; they should be pertinent to other high- and green-tech industries too (Amankwah-Amoah & Sarpong, 2016; George et al., 2015).

CONCLUSIONS

In this effort to investigate the potential of the U.K. plastic electronics industry to support a strategy for sustainable development, we also realize that sustainable development can support the plastic electronics industry. This message is relevant to all industry sectors: Sustainability and sustainable development underpinned by ecology are core requirements for success and survival. All industrial efforts, theories, methods, and models should strive to reflect ecological sustainability (Borland et al., 2016; George et al., 2015; Whiteman, Walker & Perego, 2013) and work with rather than against natural ecology and the biosphere. Failing to do so will lead along a path to long-term self-destruction. Both technological push and market pull forces must integrate sustainable development, ecocentric leadership, and a vision for full-scale ecological sustainability (Dashwood, 2014; Mittelstaedt, Kilbourne, & Schultz, 2015). George et al. (2015) emphasize this "Grand Challenge" and provide examples of how natural resource scarcity and climate change challenge businesses, governments, and industries to discover new technologies and business models; compete in natural resource markets; and collaborate across industries, nations, and cultural boundaries.

We identify a high level of general awareness of the broad definition of sustainable development, as well as recognition of the potential for plastic electronics to support it. Sustainable development currently provides little in the way of market pull to guide technological development in this industry though, and stakeholder groups express different views. This distinctiveness must inform any attempt to integrate sustainable development and drive industry developments toward sustainable development and a sustainability vision. In particular, articulating the importance of sustainable development to the U.K. plastic electronics industry and outlining key mindset and behavioral changes (Stam et al., 2014; Van der Werff et al., 2013) could provide a basis for a sustainability vision that can mobilize the sources of available support and thereby influence the development of wider push and pull drivers. This support should be geared toward ecocentric, rather than anthropocentric, industry innovations. The development of an ecocentric sustainability vision and associated ecocentric visionary leadership could influence strategic thinking and guide industry development (Borland et al., 2016). In this sense, the U.K. plastic electronics industry has the potential to support sustainable development, and sustainable development has the potential to support the development of the industry, so in turn,

> "We need leaders who can think big, think deeply, start small, and act fast. Thinking big is about breaking through existing boundaries; it is about imagination. You need to think deeply about problems and require applying rigor and expertise to ideas, explore and prototype. If we start small and in a sensible place, it's most likely going to catch on as an experiment. Acting fast requires us to have ambition, courage, and self-confidence. We need vision and a framework to get bold ideas to practice. What are good ways to lead change? How can we get business, government, and society to have a bolder vision and to act?" (Teng Lit Liak, Chair of the National Environmental Agency of Singapore, qtd. in George et al., 2015: 1606).

This study is limited by its exclusion of customer groups. We quickly discovered that the potential applications of plastic electronics were so broad that covering them sufficiently would have been beyond the scope of our research. In addition, we had trouble identifying an industry facilitator group skeptic; by definition, this group seeks to advance the industry. Therefore, we consciously decided not to include any such informant. Our case design also has some limitations in terms of its empirical generalization, though our research protocol achieves analytical generalization (Yin, 2009) and can be applied to other contexts.

In line with the purposes of exploratory case study research (Yin, 2009), we also propose a series of topics that warrant further research; exploring them could confirm the generalizability of our findings, within and across industries. A pressing task is to articulate the benefits and costs of integrating ecocentric sustainable development innovation into the plastic electronics value chain. Such an articulation may inform the development of effective incentives and enable the industry to better support sustainable development, and vice versa. Further studies also could investigate the feasibility of a sustainability competitive advantage, as achieved by stakeholders that adopt ecocentric sustainable development. In particular, researchers should investigate if ecocentric sustainable development innovations provide opportunities for competitive advantages, throughout the plastic electronics value chain.

Proposition 1: *Sustainable development provides opportunities for competitive advantages throughout the plastic electronics value chain.*

Another line of enquiry might determine how wider push and pull drivers of ecocentric sustainable development might be framed, according to the overall policy context and industrial support for sustainable development, as well as programs for building capacity in the industry. Can effective incentives be developed to support ecocentric sustainable development innovations in the plastic electronics industry?

Proposition 2: *Effective drivers and incentives can be developed to support sustainable development within the plastic electronics industry.*

We did not include potential end users, so further studies also should investigate this and other stakeholder groups to understand their particular characteristics and delineation. Such a review could support the articulation of benefits and costs across the plastic electronics value chain. Research also could test potential plastic electronics offers that might support ecocentric sustainable development in particularly relevant application areas, such as energy harvesting in specific urban or rural sites.

Proposition 3: *Plastic electronics provides the most suitable approach to support sustainable development through energy harvesting in urban (or rural) area "X."*

Finally, aspects of Eight 19's (2012) approach might be worthy of further study, particularly the success of its proposal to lease technology to end users. Ecocentric, leasing-based business models could be supported by the improved recyclability/reusability of the components, on a closed-loop basis.

Proposition 4: *Plastic electronics provides the most suitable approach to support sustainable development through ecocentric business models based on the leasing of products to end users, by offering greater potential to upcycle, recycle, or reuse components than competing technologies.*

This discussion leads us to identify our own "grand challenge" (George et al., 2015) and ask whether ecocentric eco-innovations truly contribute to the future sustainability of human existence, or simply promote yet more consumption, waste, and pollution. This question must be addressed to establish a true sustainability vision for plastic electronics. It also needs to be posed across various industry sectors, markets, and products (new and incumbent); in turn, we need sustainability-based business theories, models, and methods to address these issues (Borland et al., 2016; George et al., 2015; Hahn & Figge, 2011; Hahn et al., 2014; Whiteman et al., 2013).

The U.K. plastic electronics industry offers great potential to contribute to ecological sustainability, and ecocentric eco-innovation possibilities exist for sustainable product and market development. However, awareness among stakeholders is not enough; their sustainability mindsets, behaviors, and leadership need further development. These findings, together with positive business opportunities, emerging policy and regulations, international standards, and governmental capacity-building support can allow for the establishment of ecocentric visionary leadership—a sustainability vision and industry strategy that embraces ecocentric, transformative business approaches for a sustainable future for all.

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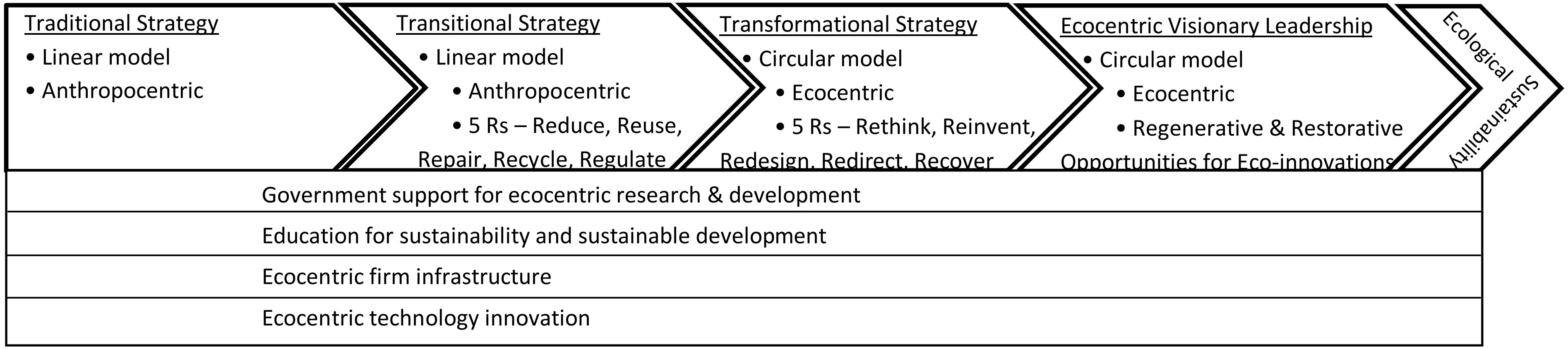
Figure 1

Conceptual Framework: Ecocentric Transformational Business Strategy for Eco-innovations



(After Borland, Ambrosini, Lindgreen & Vanhamme, 2016)

FIGURE 2

Embedded, multiple-case study design

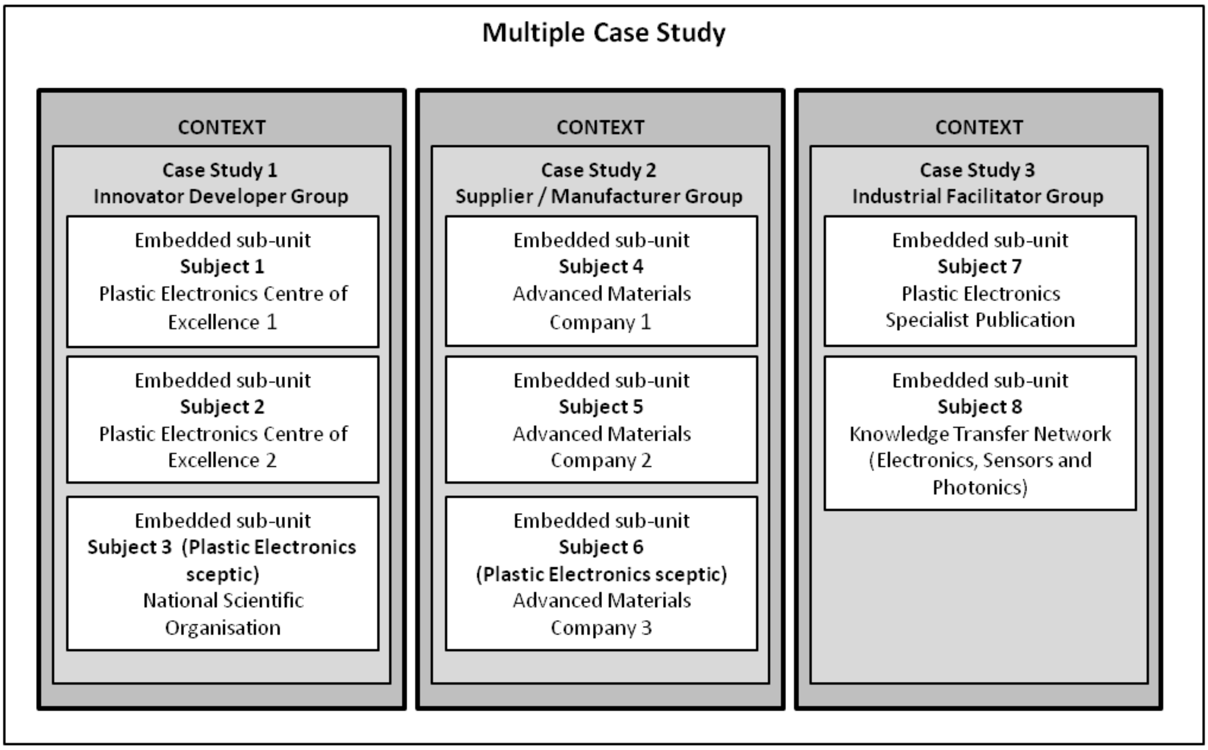


TABLE 1

High value manufacturing strategy themes (Technology Strategy Board, 2012)

Strategic Theme	Description
Resource Efficiency	Securing U.K. manufacturing technologies against scarcity of energy and other resources
Manufacturing Systems	Creating more efficient and effective manufacturing systems
Materials Integration	Creating innovative products with new manufacturing technologies
Manufacturing Processes	Developing new, agile, more cost-effective manufacturing processes
Business Models	Building new business models to realize superior value systems

TABLE 2

Cases identified by theme for each proposition

Theme	Innovative Developer	Supplier/Manufacturer	Industry Facilitator
Proposition 1: Stakeholders in the U.K. plastic electronics industry express different levels of awareness of sustainable development.			
Definition of sustainable development including aspects of ecology, resource depletion, economic prosperity, and personal well-being	✓		✓
Need to develop a new consumer mindset, rather than assume a technical solution can be developed	✓		
Materials, including concerns for life-cycle analyses of materials		✓	
Sustainable development as a positive opportunity		✓	
Sustainable development not necessarily seen as a priority		✓	
Proposition 2: Stakeholders in the U.K. plastic electronics industry have different conceptions of the potential of plastic electronics for sustainable development.			
Varied potential applications of plastic electronics to support sustainable development identified	✓	✓	✓
Eight 19 as a good example of plastic electronics supporting sustainable development	✓	✓	✓
Potential of sustainable development as a source of differentiation and competitive advantage		✓	
Recyclability and reduced toxicity of plastic electronics (including challenge by skeptic)		✓	
Potential effect of plastic electronics on wider industry through reduced labor costs		✓	✓
Need for strategic development support for plastic electronics			✓
Proposition 3: Stakeholders in the U.K. plastic electronics industry have different beliefs about the awareness of end users of the potential of plastic electronics for sustainable development.			
Low awareness of end users of the potential to support sustainable development	✓	✓	✓
Need to consider competing technologies	✓	✓	✓
Importance of delivering real benefits to end users for the industry to develop	✓	✓	✓
More need to increase awareness of the potential for plastic electronics to support sustainable development	✓	✓	✓
Need to fund increasing awareness of end users			✓
Concerns about the definition of plastic electronics	✓		✓
Limitations of plastic electronics	✓		
Development of the industry should be based on niche applications	✓		
End users do not consider sustainability a priority		✓	
Importance of the expected development of international standards for the industry		✓	