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RESEARCH PAPER

Exploring value change

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ABSTRACT
This article aims to explore the use of cross-impact balances (CIB) to identify scenarios of value change. The possibility of value change has received little attention in the literature on value-sensitive design (VSD). Examples of value change include the emergence of new values and changes in the relative importance of values. Value change could lead to a mismatch between values embedded in technology and the way they are currently considered in society. Such a mismatch could result in a lack of acceptability of technologies, increasing social tensions and injustices. However, methods to study value change in the VSD literature are rare. CIB is a scenario tool that can study systems characterized by feedback loops that are hard to describe mathematically. This is often the case when aiming to define values and their relationships. We demonstrate the use of CIB to identify scenarios of value change using two cases: digital voice assistants and gene drive organisms. Our findings show that CIB is helpful in building scenarios of value change, even in instances where the operationalization of values is complex. CIB also helps us to understand the mechanisms of value change and evaluate when such mechanisms occur. Finally, we find that CIB is particularly useful for social learning and explanatory modelling. CIB can therefore contribute to the design of value-sensitive technologies.

Introduction

Value-sensitive design (VSD) is a well-established approach to the design of technology that accounts for human values. The literature on VSD argues that technologies are 'value-laden' (Friedman, 1996; Manders-Huits, 2011). A lack of consideration of values in the design of technologies may lead to problems of acceptability and social injustice (Gauttier, 2019). VSD relies on an integrative tripartite methodology to address values in technologies. First, the conceptual phase identifies important values and stakeholders. Second, the technical investigation explores the options to address values and value conflicts, and finally, the empirical investigation gathers more information about stakeholders' perceptions of values and adequate technological options.

VSD lacks methods to anticipate changing values (van de Poel, 2021). Phenomena of value change include the emergence of new values; for example, the value of environmental sustainability in the 1980s (WCED, 1987; van de Poel, 2021). They also include changes in the relative importance of values, such as the value of safety in nuclear energy production after accidents (van de Poel *et al*., 2020). Value change could lead to a mismatch between values embedded in technologies and how they are considered in society. This mismatch may lead to societal discontent towards certain technologies, major institutional reforms and (costly) infrastructural changes. Numerous methods

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have been proposed to address values in technologies (see Friedman *et al*., 2017), but few have addressed the role of value change.

We explore the use of cross-impact balances (CIB) to identify scenarios of value change. CIB is a semi-quantitative method used to generate future scenarios (Helmer, 1981). This method is especially useful when it is difficult to describe key systems elements through mathematical formulations. This is often the case when trying to build scenarios involving values. Values tend to be latent concepts; their operationalization for specific cases is often uncertain and, in some cases, even contested. CIB relies on numerical descriptions of the relationships between system elements to generate scenarios. Plausible stable system states (i.e., credible scenarios of value change) are identified by evaluating their internal consistency.

This article is structured as follows. The next section introduces VSD and describes the challenge of anticipating value change, and the following section presents the CIB method and demonstrates how the consistency of scenarios can be evaluated. This is followed by two illustrative cases on digital voice assistants and gene drive organisms to illustrate the use of CIB to explore the changing importance of values. Next is a discussion on the adequacy and limitations of CIB to explore value change and finally an examination of the relevance of our work for the VSD literature which identifies future research steps.

Value-sensitive design and value change

Value-sensitive design

Value-sensitive design (VSD) is a well-established approach to support the creation of morally acceptable technologies. The literature on VSD claims that technologies are value-laden (Friedman, 1996; Manders-Huits, 2011). Values can be defined as 'lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or realise a good society' (van de Poel and Royakkers, 2011, p.72). Technologies and values are related in at least two ways. First, the deployment and use of technologies may seriously affect critical societal values; for example, privacy issues of voice assistant devices (Hoy, 2018) or safety issues caused by natural gas extraction (Voort and Vanclay, 2015). But values may also be drivers of technological development such as new encryption methods to resolve privacy issues or passive safety systems for nuclear power (Bodansky, 2005). VSD proactively considers values in the design of technologies (Friedman and Kahn, 2000). A better alignment between values embedded in technologies and how they are regarded in society is beneficial for their moral acceptability and social acceptance (Taebi, 2016; van de Poel, 2016).

To address values in technology, VSD relies on an integrative methodology consisting of conceptual, technical and empirical investigations. The conceptual investigation aims to identify the values at stake, those enhanced, threatened or transformed by the new technology (Manders-Huits, 2011). It also entails understanding the meaning of these values in the context in question and distinguishing stakeholders directly and indirectly affected by the technology (Friedman, 2004). The technical investigation focuses on how the technology relates to previously identified values (Friedman *et al*., 2001). Various design options are evaluated based on their capacity to offer a better balance between conflicting values. The objective of the empirical investigation is to complement conceptual and technical investigations (Oosterlaken, 2014). Information is gathered about stakeholders' perception of values and the technology in question, thereby supporting a conceptualization of values that takes the context of technological deployment into account. Conceptual, technical and empirical investigations are typically carried out iteratively (Manders-Huits, 2011).

VSD does not dictate a strict range of tools to perform such analyses, but can be used as a framework to guide the consideration of values in technologies (Manders-Huits, 2011; Oosterlaken, 2014; Pesch, 2015). Friedman, Hendry and Borning (2017) surveyed 14 methods recurrently used in VSD. These methods are used for stakeholder identification (e.g., direct and indirect stakeholder analysis), value identification (e.g., value source analysis), value elicitation (e.g., value scenario and value sketch) and design (e.g., value dams and flows and envisioning cards). In addition, other more standard methods, such as semi-structured interviews, surveys, quasi-experimental designs and longitudinal case studies (Davis and Nathan, 2015) used in social science have been frequently used in VSD. The fact that VSD is not explicit about which methods to use has sometimes been criticized in the literature. These choices may come with severe methodological, operational and moral connotations (Pesch, 2015).

Value change

A research gap in the literature on VSD is the possibility of value change. The literature on VSD has often assumed values to be stable during the deployment and use of technologies (van de Poel, 2021). While values are considered to be relatively stable over time (van de Poel and Royakkers, 2011), they can still change over relatively long periods. Examples given in the literature include the value of environmental sustainability, which has become increasingly important since the 1980s because of the increasing effects of climate change (WCED, 1987; van de Poel, 2021). Smits *et al.* (2019) explains how the introduction of the 'safe cigarette', which has a better filter and contains lower levels of nicotine, led to the redefinition of the value of health from 'healthy equals non-smoking' to 'healthy equals safe cigarettes'. De Wildt, van de Poel, and Chappin (2022) show that values considered relevant during the lifecycle of technologies change over time, typically from more functional and economic to more moral and societal. Over time, value change could lead to a mismatch between the way values are considered in society and how they are embedded in technologies (van de Poel, 2020b). Discontent about values may result in a lack of technology adoption, increased social tension and injustice and significant institutional reform (Gauttier, 2019; de Wildt *et al.*, 2021a).

We identify three strategies for value change design. The first is to anticipate value change. Boenink, Swierstra and Stemerding (2010) propose a framework to anticipate controversies caused by emerging technologies. They build techno-ethical scenarios using literature surveys and the NEST-ethics tool (Swierstra and Rip, 2007) to explore future interactions between technology and morality. A limitation of scenario analysis is that it cannot always anticipate all possible future scenarios for changing values (van de Poel, 2017). The second strategy is the use of adaptive design. Designs can be made modular to anticipate changes in the expectation and use of a technology (van de Poel, 2021). The third strategy is to monitor value change. Umbrello and van de Poel (2022) propose a 'threefold modified VSD approach' in which an essential step is to extend the VSD process to consider the full lifecycle of technologies. The approach allows us to consider unforeseen value consequences of technologies and potential redesign.

Anticipating value change

This study focuses on the strategy of anticipating value change. Whether and how value change can be anticipated largely depends on the phenomena underlying such value change. For example, we expect that the emergence of the value of sustainability in the 1980s is essentially a macro-level phenomenon resulting from increasing human economic activity and the depletion of resources (Meadows *et al.*, 1972). On the other hand, the redefinition of the value of health seems to be more market-specific. It is expected to result from the interaction between consumer needs and product (re)development. We identify three considerations when aiming to anticipate value change.

The first is to clarify how we understand value change. Various scientific fields tend to have different understandings of values and, therefore, value change (van de Poel, in this issue). We can distinguish descriptive and normative notions of values. Descriptively, values can be understood as a part of a human being. Together with norms and attitudes, they may explain individual behaviour (Stern *et al.*, 1999). Value change can also be viewed as a social or cultural phenomenon. Values emerge as a result of human interaction and form guidelines for behavioural rules in a social context. Van de Poel (in this issue) identifies two accounts of value change. The first entails a normative judgement of a particular (descriptive) case of value change. For example, is it desirable that the value of health has been redefined in the context of smoking? The second is about the possibility of normative value change. An ongoing discussion is whether such normative values can change if not understood as a function of human desires. Multiple understandings of value change can focus on various types of factors and phenomena. These, in turn, pose different requirements for the tools needed to anticipate value change.

The second consideration is which phenomena of value change need to be anticipated. Van de Poel's article identifies five types of value change: (1) emergence of new values, (2) changes in what values are relevant for the design of a particular technology, (3) changes in the priority or relative importance of values, (4) changes in how values are conceptualized, (5) changes in how values are specified and translated into norms and design requirements. Different approaches may be more suitable for certain types of phenomena. In complexity science, agent-based modelling (Epstein and Axtell, 1996) is a simulation method to explore the occurrence of emerging phenomena. In line with Dewey (1922), values can be understood as emerging responses to past moral problems (van de Poel, 2020a). Other simulation tools, such as system dynamics (Forrester, 1958), are especially useful when studying system behaviour resulting from feedback loops. For example, such tools could be used to explore how the relative importance of (competing) values evolves over time. Finally, text-mining methods can help us to understand how the conceptualization of values changes over time. For example, de Wildt, van de Poel and Chappin (2022) demonstrate how probabilistic topic models (Blei and Lafferty, 2009) can be used to explore evolving conceptualizations of privacy.

The third consideration is how well we can describe the phenomena leading to the value change that we aim to anticipate. The literature on scenarios explains that how much we know about a phenomenon depends on the extent to which we can describe the relationships among factors leading to that phenomenon (Weimer-Jehle, 2006; Schweizer and Kurniawan, 2016). Quantitative methods can be used if the relationship between factors leading to value change can be described through mathematical formulations. On the other hand, storylines are typically utilized when relationships can only be described using soft system knowledge. Fundamentally, the use of specific scenario tools is not strictly limited to a particular type of phenomenon (Börjeson *et al.*, 2006). However, quantitative tools may oversimplify certain phenomena because of the need to formalize the system using mathematical formulations (Schweizer and Kurniawan, 2016). Furthermore, the use of (typically) a few storylines (i.e., a qualitative tool) may only allow us to depict a limited space of possibilities (Schweizer and Kriegler, 2012).

The semi-quantitative cross-impact balances scenario method

The cross-impact balances (CIB) method provides a modelling approach when a theory of how different events affect each other does not exist (Helmer, 1981) or is low consensus. CIB is particularly adequate to anticipate changes in the relative importance of values when influenced by a combination of diverse factors (e.g., a combination of economic, social and technological factors). For the list of considerations proposed here, CIB could be used for both descriptive (i.e., how values are changing) and normative scenarios (i.e., how values ought to change). For descriptive notions, CIB leans more towards value change as a social or cultural phenomenon as it is expected to result from a more extensive diversity of factors than essentially psychological ones. Being a semi-quantitative method, CIB offers a good balance between the difficulty of defining relationships among these factors utilizing mathematical formulations and the benefits of exploring a broader range of possible future scenarios. It strikes this balance through a systematic search of a large number of scenarios (up to 10 billion). Furthermore, CIB is well equipped to explore phenomena of changes in the relative importance of values as it can reproduce the effects of feedback loops based on soft systems knowledge.

Scenarios in CIB are both descriptions of simultaneous outcomes (e.g., it is raining; I have an umbrella) and sets of causal chains underpinning each outcome (e.g., 'When it is raining, I take my umbrella'). For a straightforward scenario of whether a person has his umbrella when it rains, CIB is not terribly informative. However, when scenarios consist of a half-dozen descriptors or more, the human brain becomes overwhelmed by the many possible combinations of outcomes and whether their underlying causal chains in a storyline will result in internally logically consistent scenarios. Humans are able to generate plausible stories from lists of many factors; however, such stories tend to reflect previous experiences (Schweizer, 2020). The algorithmic approach of CIB helps human scenario analysts think outside the box of historical experience as well as correct wishful thinking that might operate when scenario analysts identify a favourite scenario. In recent years, CIB has gained popularity. Examples of applications in the energy domain include scenarios for the European energy market (Kunz and Vögele, 2017), energy demand in Germany (Vögele *et al.*, 2017) and vehicle-to-grid technology (Knupfer *et al.*, 2016).

Before elaborating further on how CIB works and its relationship to other scenario tools, let us generally clarify what scenarios are. They are 'tools for analysing plausible alternative future trajectories in a complex system' (Schweizer and Kurniawan, 2016). They offer ways to characterize and communicate the uncertainty that characterizes different alternative decisions (Bryant and Lempert, 2010). Three categories of scenarios can be found: predictive, explorative and normative (Börjeson *et al.*, 2006). Well-known scenario development techniques, running the gamut from qualitative to quantitative, include Delphi methods, morphological analysis and explanatory modelling. Often, quantitative scenarios employ qualitative scenarios, or storylines, in order to select sets of exogenous assumptions for the quantitative analysis or to communicate analytical findings (Schweizer, 2019). Ultimately, scenarios must be salient to those who might use them for making decisions, so participatory approaches are common for eliciting expert or stakeholder judgements about socio-economic properties and preferences as well as possible economic and technological developments. In general, a key goal of scenario analysis is to make visible plausible transitions from the status quo (i.e., traditional organizational models) to new organizational models or relationships.

CIB makes such transitions visible in a particular way. It identifies alternative stable system states, or 'system attractors'. Often, the status quo is one attractor, but alternative stable system configurations are also possible. CIB identifies alternative counterfactual 'internally consistent' scenarios and provides clues for how one might transition away from a status quo attractor to a more desirable alternative. CIB is also useful for sorting 'credible' storylines from others that may be plausible *prima facie,* but are less internally consistent. The defining characteristic of stable CIB scenarios is that the internal causal chains of their scenario states as outcomes (i.e., system states as dependent variables) conflict as little as possible with the causal chains exerting net influences on the system (i.e., system states acting as independent variables).

CIB works as a systematic approach for collecting, collating and processing qualitative information about system behaviour. Schweizer and Kriegler (2012) identify the following three steps in making a CIB matrix:

1. **System definition.** The first step of CIB is to define the scenario factors that describe the system (so-called 'descriptors') and alternative possible descriptor states. Descriptors are system variables that may contribute to how a scenario will unfold, e.g., education, solidarity, production. Descriptor states are the possible outcomes of each descriptor; e.g., high, low, regional, global.
2. **Collection of judgements.** The second step of CIB is to collect judgements about how each descriptor state directly influences others. Such judgements are collected pairwise and are akin to pair-force interactions for coupled first-order differential equations describing the system. Because CIB systematized soft-systems knowledge in the CIB matrix, judgements of influence are noted as discrete numbers on a Likert scale, usually between -3 and 3. High numbers (e.g., 3) represent the strongest positive, reinforcing influence, while low numbers

(e.g., -3) represent the strongest negative, dampening influence. A judgement score of 0 indicates no direct influence. Only direct influences are considered in the model to ensure that indirect effects of one variable over another are not amplified artificially.

3. **Evaluation of internal consistencies of scenarios.** CIB aims to identify internally consistent scenarios. In CIB, a scenario is a particular combination or set of descriptor states. A scenario is internally consistent if its underlying drivers (i.e., causal chains) are self-reinforcing. This property makes the scenario stable in contrast to scenarios without this property (i.e., transient scenarios; see von Reibnitz, 1988). To calculate the internal consistency of scenarios, the method presented by Weimer-Jehle (2006) is used, which applies a systemic calculation akin to the anti-derivatives of the pair-forces in the CIB matrix combined with a logical test. The output of the evaluation calculation is a numerical score for the internal consistency of the scenario. The CIB matrix can also be interpreted to explain what causal chains make the scenario internally consistent (or inconsistent).

CIB is typically used to analyse systems with ‘political, economic, technological, or social change’ elements (Weimer-Jehle, 2008). Importantly, CIB does not aim to provide predictive scenarios of transient system behaviour such as through succession analysis. Instead, CIB offers suggestive scenarios based on a more flexible way of accounting for soft systems relationships between system elements, allowing the inclusion of more intuitive and tacit knowledge into the model. Furthermore, the fact that relationships between factors are described numerically makes possible analyses about scenario quality (i.e., internal consistency). This makes CIB especially interesting and informative in a multidisciplinary or novel context.

Although CIB can find ‘emergent’ scenarios because of system influences that holistic human judgement is prone to overlook, CIB is not able to explore the emergence of new values beyond the scope of the analysis initially set in Step 1 since it assumes that all factors comprising the scenario are the same throughout the simulation. Instead, in the studies below, it was found that internally consistent CIB scenarios described possible end states concerning the relative importance of (competing) values.

Illustrative cases

In this section, we demonstrate how scenarios of value change can be explored using CIB. With this method, we concentrate on changes in the relative importance of values as a type of value change. We consider value change as a social or cultural phenomenon. A value becomes essential when it is associated with many problems. For example, environmental sustainability becomes a more critical value when there are more environmental problems. This value would then typically gain consideration in individual and organizational decision-making.

Our demonstration is based on two illustrative cases. These cases illustrate the potential contribution of CIB to design value-sensitive technologies and evaluate the limits of this method to explore different cases of value change. The first case is digital voice assistants. We explore how changes in the importance of privacy and sociality might affect whether individuals choose to disclose them in the presence of their social networks. The second case is gene drive organisms. We examine what changes in the importance of public health and ecological stability could mean for the desirability of this technology. In each case, we describe scenarios and implications for the design of value-sensitive technologies.

Case one: digital voice assistants

CASE DESCRIPTION

The adoption of digital voice assistants (DVA) has increased rapidly in recent years, reaching 320 million units in 2020 (Staticta, 2021). The best known examples of DVAs include Amazon’s Alexa, Google's Assistant and Apple's Siri. DVAs can be used to perform specific actions based on verbal requests. For example, actions can include sending and reading text messages and emails, providing information about the weather or calendar entries, and controlling media playback (Hoy, 2018). DVAs essentially perform the following three processes: 'recognising speech, interpreting speech, and producing speech' (Hamer *et al.*, 2020). Although speech recognition (noticing that a user makes a request) and speech production (providing verbal information) abilities have improved in recent years, speech interpretation (understanding user requests) still requires further development.

The introduction of DVAs has led to many concerns about potential privacy issues. Private information may be revealed while making a request to the DVA. From the user's perspective, this can also happen unintentionally, as the appliance must continually overhear conversations to be able to detect new user requests. In addition, it is sometimes unclear how user data are used by manufacturers and authorities (Hoy, 2018). Risks of accidental data recording are always possible as a result of interpretation errors, and stolen data could be used at the expense of users' personal safety. DVAs may also affect behavioural norms in social interactions (Hamer *et al.*, 2020; Kudina, 2021). Given potential privacy issues, an important question is whether owners of DVAs will choose to disclose their presence when visited at home by their social networks.

Whether owners choose to self-disclose can be understood in terms of two values: privacy is a primary concern caused by DVAs, and sociality is the extent to which owners feel responsible for disclosing a DVA's presence and taking necessary action. From a value change perspective, the importance of sociality is expected to increase as privacy issues become more alarming. Understanding whether sociality might become a significant value is essential for designers and manufacturers to evaluate whether options need to be added to DVAs to help owners disclose their presence and adjust privacy settings. The absence of such options could hamper the economic success of DVAs.

CIB MATRIX

We build a CIB matrix to explore how the importance of privacy and sociality might evolve in the context of DVAs. The CIB matrix was built with an expert on DVAs and values (see Appendix A). In a first step, we identified a set of descriptors that could influence the importance of each value over time. We limited the number of descriptors per value to five as any additional descriptor vastly increases the duration of filling in a CIB matrix. The expert identified a set of states for each descriptor (e.g., low importance and high importance for the value privacy). Table 1 shows the list of descriptors. In a second step, we added the relationships between the scenario descriptors and the states based on a review of the scientific literature on the topic. Any uncertainties about the relationships identified were discussed with the expert. Appendix B presents the CIB matrix.

Table 1. Descriptors and descriptors states for DVA value change

Descriptors	**Descriptor states**
Privacy	*Low importance, High importance*
Sociality	*Low importance, High importance*
Technological opportunities	*No change, Increase*
Social acceptance in social networks	*Decrease, No change, Increase*
Possibilities for privacy management	*No change, Increase*
Privacy design of technologies	*Status quo, Promoted*
Enforcement of privacy regulations	*Weak, Middle, Strong*
Range of experiences	*Moderate increase, Dramatic increase*
Social etiquette	*Sticking to old habits, Following examples of others, Setting new standards*
Openness to diversity	*Decrease, No change, Increase*

An increase in privacy problems in DVAs raises the importance of sociality as the pressure to disclose the appliance increases. Such privacy problems might also decrease the social acceptance of users' social networks. Similarly, an increase of sociality might negatively affect social acceptance and lead to new standards of social etiquette, redefining what is considered permissible in a social context. An increase in technological opportunities (i.e., combination of multiple appliances) might increase privacy issues and the range of experiences that DVAs create for users. An increase in the social acceptance of the network is likely to encourage individuals to adopt new standards of social etiquette. Possibilities for privacy management are likely to reduce sociality issues, as privacy settings can be easily adjusted if needed. A better privacy design of DVAs might restrict technical opportunities created by combining multiple appliances. Enforcing privacy regulations could encourage manufacturers to increase possibilities for privacy management and improve privacy designs. An increase in the range of experiences may typically cause more social frictions and hence issues of sociality. The willingness to set new standards of social etiquette solves sociality issues. Finally, openness to diversity encourages users to adopt new standards of social etiquette.

RESULTS

The CIB evaluation resulted in twelve consistent scenarios out of 5,184 possible combinations. These scenarios can be grouped into two clusters (see Table 2). In the first cluster, privacy and sociality have low importance. In this case, privacy regulations are enforced, leading to multiple possibilities of privacy management and good privacy designs. We can expect low importance of sociality when social networks have already accepted DVAs. As most people are accustomed to DVAs, this leads to few social frictions and hence no need to redefine social norms. In the second cluster, privacy and sociality have high importance. In this case, privacy regulations are weakly enforced, leading to limited possibilities for privacy management and weak privacy designs. The social acceptance of DVAs is low, and social etiquette standards are continuously redefined, leading to ongoing problems of sociality.

We find that the occurrence of these two clusters is explained by the existence of two feedback loops in the matrix. These loops are identified by starting from different combinations of descriptor states and progressively adjusting inconsistent states until we end up in a consistent scenario. Appendix C shows an example of this process. We find that the descriptor enforcement of privacy regulations largely determines the end state of scenarios. With a middle or strong privacy regulation enforcement, the possibilities for privacy management increase and the privacy design of DVAs improves. As a result, the importance of privacy and sociability issues decreases. Indeed, if privacy problems are low, the urge for DVA owners to disclose the presence of their appliances decreases. On the other hand, if the enforcement of privacy regulation is weak, privacy and sociality are both high in importance. Because of the increased importance of sociality*,* the lack of social acceptance of the network increases, and the reluctance to change social etiquette. Sticking to old habits reinforces sociality issues caused by the DVA.

Table 2. Clusters of consistent scenarios found for DVA value change

Descriptors	Cluster 1 (6 scenarios)	Cluster 2 (6 scenarios)
Privacy	*Low importance*	*High importance*
Sociality	*Low importance*	*High importance*
Technological opportunities	*No change*	*No change, Increase*
Social acceptance in social network	*Increase*	*Decrease*
Possibilities for privacy management	*Increase*	*No change*
Privacy design of technologies	*Promoted*	*Status quo*
Enforcement of privacy regulations	*Middle, Strong*	*Weak*
Range of experiences	*Moderate increase*	*Moderate increase*
Social etiquette	*Sticking to old habits*	*Setting new standards*
Openness to diversity	*Decrease, No change, Increase*	*Decrease, No change, Increase*

IMPLICATIONS FOR THE DESIGN OF DVAS

We aimed to explore whether privacy and sociality would become more important over time, making it more essential for designers to propose options for disclosing DVA presence and privacy adjustments. Based on our analysis, it appears that this depends on the willingness of governments to enforce privacy regulations. If they opt for enforcement, the importance of privacy and sociality will ultimately decrease, thereby making such options less critical. The model indicates that, although some sociality issues might occur, users and their social network will eventually adjust their norms to the presence of the DVA. If governments do not enforce these regulations, the importance of privacy and sociality will remain high, and options to disclose DVA presence and adjust privacy will therefore be more critical.

Case two: malaria and gene drive organisms

CASE DESCRIPTION

In 2019, an estimated 229 million cases of malaria were reported worldwide, of which 94% were in Africa (WHO, 2020). The total reported number of deaths was 409,000. Conventional prevention measures against malaria include insecticide-treated mosquito nets, residual spraying and vaccination. An alternative prevention method is gene drive organisms (GDO) (ETC Group, 2019). The principle of GDO is to spread adjusted genetic material through particular species. In the case of malaria, GDO could alter the DNA of mosquitos, for example, by ensuring that the majority of offspring are male. As this gene is passed through generations through sexual reproduction, this could help to reduce mosquito populations. Thus, GDO could represent a much-needed means of preventing malaria, particularly as this disease risks spreading to new geographical areas as a result of climate change (Piperaki and Daikos, 2016). However, GDO also raises severe ethical concerns. One of them is ecological instability, as GDO risks altering existing animal food chains and restricting the contribution of mosquitos in the pollination process of plants (National Academies of Sciences Engineering and Medicine, 2016; ETC Group, 2019). Additionally, it is unclear to what extent adjusted genes could unintentionally spread to other species.

The tension between the positive health effects of GDO and the potential threats to ecological stability can be viewed as a conflict between the values of public health and ecological stability. From a value change perspective, the question is how the acceptability of GDO will evolve. The acceptability of GDO is expected to increase if public health becomes more important, but to decrease if ecological stability becomes more prominent. A better understanding of the future acceptability of GDO could be helpful for companies involved in this technology and for governmental entities regulating their use.

CIB MATRIX

We built a CIB matrix to explore how the relative importance of public health and ecological stability might evolve over time in the context of GDO. The matrix is similar to the one used in case 1 and was developed with an expert on GDO and malaria (see Appendix A). Table 3 lists the descriptors. Appendix D presents the CIB, including the judgements between scenario descriptors.

An increase in the number of public health issues is expected to increase the trustworthiness of GDO science. However, the inability to resolve ecological instability issues might decrease trust in this research domain. Climate change was identified as a descriptor since temperature increases could spread malaria to new populations that do not generally impose preventive measures (Piperaki and Daikos, 2016). Climate change could also lead to significant problems of ecological instability. The use of GDO can be controlled (low impact on ecological stability) or uncontrolled (high impact). Further development of malaria vaccines will help prevent health problems, while improved medication might only be a temporary solution. The use of GDO can help reduce the mosquito population,

Table 3. Descriptors and descriptor states for GDO value change

Descriptors	Descriptor states
Public health	*Low importance, High importance*
Ecological stability	*Low importance, High importance*
Climate change	*0–2 degrees, 2–4 degrees, 4–5 degrees*
Preferred treatment	*Uncontrolled GDO, Controlled GDO, Improved medication, Improved vaccination*
Mitigation measures	*Effective pest control, Effective protection measures*
Controllability GDO	*None, Proven in lab, Proven outside lab*
Size mosquito population	*Decreasing, Controlled, Exploding*
Trustworthiness of GDO science	*Trust, Mistrust*

but may cause ecological instability (Noble *et al.*, 2017). Effective pest control can help contain the mosquito population, and effective protection measures (e.g., insecticide-treated mosquito nets, residual spraying) can be used in homes. Proofs of the controllability of GDO ensure that ecological stability concerns are addressed. An increase in the size of the mosquito population will typically increase the number of malaria cases and hence health problems. Both an increase and a decrease in the mosquito population would alter ecological stability. Finally, a decrease in the trustworthiness of GDO science will lead to preferring other treatments and mitigation methods.

RESULTS

The CIB evaluation resulted in 36 consistent scenarios out of 3,888 possible combinations. We identified eight clusters of consistent scenarios (see Table 4). In the first cluster, public health has low importance and ecological stability has high importance. This cluster occurs with improved vaccination and a temperature increase of two to four degrees attributable to climate change. The second cluster has the same levels of importance of values and occurs with improved medication or improved vaccination. The third cluster occurs with uncontrolled GDO use. In the fourth cluster, public health has high importance and ecological stability low importance. This cluster occurs with controlled GDO use. All other clusters have high importance for public health and ecological stability. The fifth cluster occurs with uncontrolled and the sixth with controlled GDO. A seventh cluster occurs with improved medication or improved vaccination as preferred treatment, while the size of the mosquito population is controlled. Finally, the eighth cluster occurs with the same preferred treatments, but with an exploding mosquito population.

We identify three mechanisms to explain the occurrence of the clusters of scenarios identified in Table 4. The first is when one scenario state acts as an independent variable when combined with a specific set of other scenario states. For example, in cluster 2, none of the scenario states (e.g., the preferred treatment method) influences the decreasing size of the mosquito population. As a result, the cluster assumes that the size of the mosquito population will decrease. Therefore, the value of health is of low importance, even if the temperature increases resulting from climate change are high. The same can be seen in cluster 8, which shows an exploding mosquito population.

The second mechanism is when a scenario state is between two opposite benefits of one single technology. In Table 4, improved medication and vaccination are always preferred when the controllability of GDO is proven in the lab (see clusters 1, 2, 7 and 8). If GDO is established outside the lab, the scenario progressively moves towards controlled GDO as the preferred treatment method, as it makes more sense from the point of view of ecological stability (e.g., cluster 4). If the controllability of GDO is not proven, the scenario progressively moves towards uncontrolled GDO (i.e., the use of GDO when its controllability is not proven) as this is better in terms of public health (e.g., cluster 3).

Table 4. Clusters of consistent scenarios found for GDO value change

Descriptors	**Cluster 1 (1 scenario)**	**Cluster 2 (6 scenarios)**
Public health	*Low importance*	*Low importance*
Ecological stability	*High importance*	*High importance*
Climate change	*2–4 degrees*	*0–2 degrees, 2–4 degrees, 4–5 degrees*
Preferred treatments	*Improved vaccination*	*Improved medication, Improved vaccination*
Mitigation measures	*Effective protection measures*	*Effective protection measures*
Controllability GDO	*Proven in lab*	*Proven in lab*
Size mosquito population	*Controlled*	*Decreasing*
Trustworthiness of GDO science	*Mistrust*	*Mistrust*
Descriptors	**Cluster 3 (6 scenarios)**	**Cluster 4 (4 scenarios)**
Public health	*Low importance*	*High importance*
Ecological stability	*High importance*	*Low importance*
Climate change	*0–2 degrees, 2–4 degrees, 4–5 degrees*	*0–2 degrees, 2–4 degrees*
Preferred treatments	*Uncontrolled GDO*	*Controlled GDO*
Mitigation measures	*Effective pest control, Effective protection measures*	*Effective pest control, Effective protection measures*
Controllability GDO	*None*	*Proven outside lab*
Size mosquito population	*Decreasing*	*Controlled*
Trustworthiness of GDO science	*Mistrust*	*Trust*
Descriptors	**Cluster 5 (1 scenario)**	**Cluster 6 (4 scenarios)**
Public health	*High importance*	*High importance*
Ecological stability	*High importance*	*High importance*
Climate change	*4–5 degrees*	*2–4 degrees, 4–5 degrees*
Preferred treatments	*Uncontrolled GDO*	*Controlled GDO*
Mitigation measures	*Effective pest control*	*Effective pest control, Effective protection measures*
Controllability GDO	*None*	*Proven outside lab*
Size mosquito population	*Decreasing*	*Controlled*
Trustworthiness of GDO science	*Mistrust*	*Mistrust*
Descriptors	**Cluster 7 (8 scenarios)**	**Cluster 8 (6 scenarios)**
Public health	*High importance*	*High importance*
Ecological stability	*High importance*	*High importance*
Climate change	*2–4 degrees, 4–5 degrees*	*0–2 degrees, 2–4 degrees, 4–5 degrees*
Preferred treatments	*Improved medication, Improved vaccination*	*Improved medication, Improved vaccination*
Mitigation measures	*Effective pest control, Effective protection measures*	*Effective protection measures*
Controllability GDO	*Proven in lab*	*Proven in lab*
Size mosquito population	*Controlled*	*Exploding*
Trustworthiness of GDO science	*Mistrust*	*Mistrust*

The third mechanism is when the initial situation cannot be resolved by even the best treatment method for certain values. This is the case for cluster 5. Uncontrolled GDO is best in terms of public health, but because of the extreme increase in temperature, public health issues cannot be resolved. A similar situation is found for cluster 6. Although controlled GDO positively impacts ecological stability, high temperatures ensure that ecological stability problems are not resolved, leading to mistrust in GDO science. The contrary can be found in cluster 4.

IMPLICATIONS FOR THE DESIGN OF GDO TECHNOLOGY

We examined how the acceptability of GDO is likely to evolve. A scenario where both public health and ecological stability have low importance (and hence where GDO would not be contested) does not occur. However, because of climate change, environmental stability problems are likely to occur. GDO can help address this issue if its controllability is proven and temperature increases are limited. However, as climate change might lead to the spread of malaria to new geographical regions, this might not be sufficient to address all health effects. Our outcomes do not imply that GDO is an imperfect solution, as public health can also be addressed by such treatments as improved medication and vaccination. However, it remains a potentially contested technology. For companies involved, this means that investments in this technology might remain risky.

Discussion

Applying scenario methods to study value change is rare in the academic literature. In this research, we evaluate the use of CIB to anticipate value change. Here we discuss four observations of the use of CIB to explore the changing relative importance of values. The first observation is that CIB helps to bypass the difficulty of turning values into scenario tools. Values tend to be latent concepts because they are broad societal convictions, and the ways they relate to technologies are often numerous and may change over time (van de Poel, 2020b). Also, a chosen operationalization might be contested, as different societal groups might have different opinions about what a value entails and how it should be realized. However, most scenario tools allow for only a unique or limited number of operationalizations for each system component. As a result, some scenario tools may not do justice to the way values are understood in society (de Wildt, 2020). By describing relationships between system components using indicators of polarity and strength, CIB obviates part of the discussion on the exact meaning of a value while still yielding useful information about systemic value change. For example, two people might not agree whether sociality in the context of DVAs is addressed sufficiently by disclosing its presence to visiting friends and relatives, or whether it also requires suggesting the adjustment of privacy settings. Still, both might agree that the existence of DVA privacy issues might require action to ensure sociality.

The second observation is that CIB helps to explore mechanisms of value change. Because the possibility of value change is relatively new in the VSD literature (van de Poel, 2021), little work has yet been done to understand the underlying mechanisms. De Wildt, van de Poel, and Chappin (2022) analyse empirically value change using probabilistic topic models, but have not entirely verified hypotheses about the reasons for their occurrence. Through the modeller-inserted mechanisms of value change into the CIB matrix model (by selecting descriptors and pairwise judgements of direct influences), the analysis of model outcomes allows us to understand which mechanisms are most prominent and under which conditions they occur. For example, in the DVA case, two descriptors act as independent variables (i.e., enforcement of privacy regulations and openness to diversity). However, it appears that enforcement of privacy regulations is the most influential as it explains whether the importance of privacy and sociality becomes high or low over time. In the same case, we also observe a stabilizing effect. The high importance of sociality leads to setting new standards of social etiquette. If privacy problems are addressed, sociality issues can be resolved, thereby decreasing the importance of this value. In the GDO case, two feedback loops lead to the use of either controlled or uncontrolled GDO. The different states for the controllability of GDO essentially explain how GDO is used.

The third observation is that CIB seems to be more adapted to anticipate certain phenomena of value change. We explained that different scenario tools might be more suitable to represent different types of phenomena. While it is true that the characteristics of the phenomena to be simulated should guide the selection of the scenario tool used, it is often the case that no scenario tool is ideal. For example, CIB is useful for representing the effects of feedback loops if mathematical formulations cannot adequately describe the relationship among system elements. However, it is hardly adequate to characterize the impact of heterogeneity and interactions of multiple individuals on system behaviour. This means that CIB results might represent general trends for social values or the values of an average person. For example, in the DVA case, we assume that increased privacy issues lead to a lack of social acceptance of owners' social networks. However, individuals might assign a different importance to privacy and therefore may not be concerned about privacy issues. Furthermore, through agent-level interactions, these individuals might also influence each other in their opinions about privacy. In some cases, this might not lead to a higher importance of sociality, even if the importance of privacy is high; such agent-level dynamics, which CIB cannot detect, might thus affect the quality and diversity of scenarios found. While methodological limitations of different scenario tools are inevitable, it is important to be aware of their potential effect on model outcomes.

The fourth observation is that the contribution of CIB differs according to the purpose of the model. Edmonds *et al.* (2018) identify seven common model purposes: prediction, explanation, description, theoretical exploration, illustration, analogy and social learning. As stated previously, for predictive purposes, the contribution of CIB is limited when aiming to produce a roadmap for transitioning from the status quo to a more desirable scenario. At best, CIB results can be considered suggestive. The difficulty of accounting for the number and heterogeneity of factors may primarily affect the accuracy of predictions. The contribution of CIB is stronger when it comes to explanation purposes; for example, understanding why certain phenomena of value change occur. CIB can help to recreate certain phenomena and to understand in which circumstances they occur. In the DVA case, we identified which independent variables explain most of the occurrence of consistent scenarios. Another model purpose for which CIB is well suited is social learning. CIB is a relatively intuitive form of model building. In contrast to several scenario tools, building the model does not require programming skills. We relied on simple numerical descriptions of the relationships among factors. This is an attractive advantage for its use in scientific communities with less experience of simulation methods. CIB also offers a platform for discussion and reflection among stakeholders.

Conclusions

We have evaluated the use of CIB in exploring value change in value-sensitive design. We studied two cases, one on digital voice assistants, the other on gene drive organisms, to perform this evaluation. CIB is a valuable method as it bypasses the difficulty of turning values into scenario tools. CIB relies on Likert scales to provide numerical descriptions of the relationships among system components instead of potentially uncertain and contested mathematical formulations of operationalizations of values. CIB also helps explore the effects of various mechanisms of value change and aids understanding which are dominant in explaining scenarios of value change. The method is suitable for representing value change mechanisms that can be described in terms of feedback loops. However, its ability to represent the effect of heterogeneity and interaction among individuals is limited. Finally, CIB is particularly useful to explain mechanisms of value change and for social learning.

This work contributes to the literature on VSD in two ways. First, it proposes a relatively simple tool to explore possible future value change. Our case study on DVA shows that CIB can identify what expectations users are likely to have from technologies to evaluate whether technological designs should account for these possible changing expectations. Our GDO case study demonstrates that CIB is useful for assessing how its acceptability might evolve based on changing relative importance of values. This information is helpful for private companies when evaluating investment risks, and for governmental organizations when regulating technological usage. Second, CIB can help us understand the mechanisms underlying value change and the circumstances under which they occur. An analysis of CIB outcomes shows which mechanisms of feedback loops and which initial conditions are responsible for how values and their importance can change over time.

We identify three future research steps for the use of scenario tools, in particular CIB, to explore value change. First, more thorough applications of CIB to cases of value change are needed to learn about its benefits and limitations. For example, its application in a multi-stakeholder context could help us understand how to cope with conflicting opinions of the descriptors and judgement affecting value change (a theoretical discussion of potential benefits can be found in Scheele *et al.* (2018). Second, more work is needed to understand the mechanisms of value change. Various scenario tools are suitable for such analyses, such as agent-based modelling and system dynamics. Combining these tools with other methods, such as exploratory modelling and analysis (Kwakkel and Pruyt, 2013) could help systematically categorize patterns of value change. Third, exploring the typical difficulties encountered when modelling values and value change is necessary. We believe that operationalizing (latent, dynamic and contested) values is a significant challenge. Such work could significantly contribute to the use of scenario tools in VSD.

Appendices

Appendix A. List of interviewees

Case	Interviewee	Organization
Digital voice assistants	Assistant professor of ethics and philosophy of technology	Delft University of Technology, Faculty of Technology, Policy and Management
Gene drive organisms	Assistant professor of biotechnology and society	Delft University of Applied Sciences

Appendix B. CIB matrix on digital voice assistant

CIB_value_change_voice_assistan...																								
Privacy:																								
Low importance			3	-3	0	0	-2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
High importance			-3	3	0	0	2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociality:																								
Low importance	0	0			0	0	-2	0	2	0	0	0	0	0	0	0	0	0	2	-2	-2	0	0	0
High importance	0	0			0	0	2	0	-2	0	0	0	0	0	0	0	0	0	-2	1	3	0	0	0
Technological opportunities:																								
No change	0	0	0	0			0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0
Increase	-2	2	0	0			0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
Social acceptance in social network:																								
Decrease	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-2	0	2	0	0	0
No change	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-1	2	-1	0	0	0
Increase	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	2	0	-2	0	0	0
Possibilities for privacy management:																								
No change	-2	2	-2	2	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
Increase	2	-2	2	-2	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
Privacy design of technologies:																								
Status quo	-3	3	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0
Promoted	2	-2	0	0	1	-1	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0
Enforcement of privacy regulations:																								
Weak	0	0	0	0	0	0	0	0	0	2	-2	2	-2				0	0	0	0	0	0	0	0
Middle	0	0	0	0	0	0	0	0	0	-1	1	-1	0				0	0	0	0	0	0	0	0
Strong	0	0	0	0	0	0	0	0	0	-3	3	-2	3				0	0	0	0	0	0	0	0
Range of experiences:																								
Moderate increase	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Dramatic increase	0	0	-3	3	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Social etiquette:																								
Sticking to old habits	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Following example of others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Setting new standards	0	0	2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Openness to diversity:																								
Decrease	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-3	-3			
No change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Increase	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	3	3			

Appendix C. Succession test for digital voice assistant case

Step 1

Selection:	x		x		x		x			x		x		x			x		x			x		
Balance:	-5	5	-3	3	0	0	-4	0	4	2	-2	2	-2	0	0	0	-1	-2	2	-5	-3	0	0	0
Privacy:																								
Low importance			3	-3	0	0	-2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociality:																								
Low importance	0	0			0	0	-2	0	2	0	0	0	0	0	0	0	0	0	2	-2	-2	0	0	0
Technological opportunities:																								
No change	0	0	0	0			0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0
Social acceptance in social network:																								
Decrease	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-2	0	2	0	0	0
Possibilities for privacy management:																								
No change	-2	2	-2	2	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
Privacy design of technologies:																								
Status quo	-3	3	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0
Enforcement of privacy regulations:																								
Weak	0	0	0	0	0	0	0	0	0	2	-2	2	-2				0	0	0	0	0	0	0	0
Range of experiences:																								
Moderate increase	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Social etiquette:																								
Sticking to old habits	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Openness to diversity:																								
Decrease	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-3	-3			

Step 2

Selection:		x		x	x				x	x		x		x			x		x			x		
Balance:	-5	5	-9	9	0	0	4	0	-4	2	-2	2	-2	0	0	0	-1	-2	2	-2	-2	0	0	0
Privacy:																								
High importance			-3	3	0	0	2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociality:																								
High importance	0	0			0	0	2	0	-2	0	0	0	0	0	0	0	0	0	-2	1	3	0	0	0
Technological opportunities:																								
No change	0	0	0	0			0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0
Social acceptance in social network:																								
Increase	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	2	0	-2	0	0	0
Possibilities for privacy management:																								
No change	-2	2	-2	2	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
Privacy design of technologies:																								
Status quo	-3	3	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0
Enforcement of privacy regulations:																								
Weak	0	0	0	0	0	0	0	0	0	2	-2	2	-2				0	0	0	0	0	0	0	0
Range of experiences:																								
Moderate increase	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Social etiquette:																								
Sticking to old habits	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Openness to diversity:																								
Decrease	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-3	-3			

Step 3

Selection:		x		x	x		x			x		x		x			x		x			x		
Balance:	-5	5	-9	9	0	0	4	0	-4	2	-2	2	-2	0	0	0	-1	-2	-2	-2	2	0	0	0
Privacy:																								
High importance			-3	3	0	0	2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociality:																								
High importance	0	0			0	0	2	0	-2	0	0	0	0	0	0	0	0	0	-2	1	3	0	0	0
Technological opportunities:																								
No change	0	0	0	0			0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0
Social acceptance in social network:																								
Decrease	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-2	0	2	0	0	0
Possibilities for privacy management:																								
No change	-2	2	-2	2	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
Privacy design of technologies:																								
Status quo	-3	3	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0
Enforcement of privacy regulations:																								
Weak	0	0	0	0	0	0	0	0	0	2	-2	2	-2				0	0	0	0	0	0	0	0
Range of experiences:																								
Moderate increase	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Social etiquette:																								
Sticking to old habits	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Openness to diversity:																								
Decrease	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-3	-3			

Step 4

Selection:		x		x	x		x			x		x		x			x				x	x		
Balance:	-5	5	-5	5	0	0	4	0	-4	2	-2	2	-2	0	0	0	-1	-2	-2	-2	2	0	0	0
Privacy:																								
High importance			-3	3	0	0	2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociality:																								
High importance	0	0			0	0	2	0	-2	0	0	0	0	0	0	0	0	0	-2	1	3	0	0	0
Technological opportunities:																								
No change	0	0	0	0			0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0
Social acceptance in social network:																								
Decrease	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-2	0	2	0	0	0
Possibilities for privacy management:																								
No change	-2	2	-2	2	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
Privacy design of technologies:																								
Status quo	-3	3	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0
Enforcement of privacy regulations:																								
Weak	0	0	0	0	0	0	0	0	0	2	-2	2	-2				0	0	0	0	0	0	0	0
Range of experiences:																								
Moderate increase	0	0	-2	2	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
Social etiquette:																								
Setting new standards	0	0	2	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
Openness to diversity:																								
Decrease	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-3	-3			

Appendix D. CIB matrix on malaria and gene drive organisms

CIB_gene_drive.scw																					
Public health:																					
Low importance			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1
High importance			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1
Ecological stability:																					
Low importance	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-2
High importance	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	2
Climate change:																					
0-2 degrees	-1	1	-1	1				0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-4 degrees	-2	2	-2	2				0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-5 degrees	-3	3	-3	3				0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preferred treatment:																					
Uncontrolled GDO	0	0	0	0	0	0	0					0	0	0	0	0	2	-1	-1	0	0
Controlled GDO	0	0	0	0	0	0	0					0	0	0	0	0	-1	2	-1	0	0
Improved medication	1	-1	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0
Improved vaccination	2	-2	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0
Mitigation measures:																					
Effective pest control	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	1	-1	0	0
Effective protection measures	1	-1	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0
Controllability GDO:																					
None	0	0	0	0	0	0	0	3	-3	0	0	0	0				0	0	0	0	0
Proven in lab	0	0	0	0	0	0	0	1	-1	0	0	0	0				0	0	0	0	0
Proven outside of lab	0	0	0	0	0	0	0	-3	3	0	0	0	0				0	0	0	0	0
Size mosquito population:																					
Decreasing	3	-3	-2	2	0	0	0	0	0	0	0	0	0	0	0	0				0	0
Controlled	-1	1	2	-2	0	0	0	0	0	0	0	0	0	0	0	0				0	0
Exploding	-3	3	-2	2	0	0	0	0	0	0	0	0	0	0	0	0				0	0
Trustworthiness of GDO science:																					
Trust	0	0	0	0	0	0	0	1	1	-1	-1	-1	-1	0	0	0	0	0	0		
Mistrust	0	0	0	0	0	0	0	-1	-1	1	1	1	1	0	0	0	0	0	0		

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