The role of sustainability in the UK synthetic biology programme

Nicholas E. Matthews ^{a, b, c}

^a Manchester Institute of Innovation Research, Alliance Manchester Business School, The University of Manchester, Booth Street West, Manchester, M15 6PB, UK

^b Manchester Synthetic Biology Research Centre for Fine and Speciality Chemicals, Manchester Institute of Biotechnology, The University of Manchester, 131 Princess Street, Manchester, M1 7DN, UK

^c School of Chemical Engineering and Analytical Science, The University of Manchester, The Mill, Sackville Street, Manchester, M1 3AL, UK

Abstract

Policy interventions in support of emerging technologies are often justified through their potential to support sustainability transitions. Synthetic biology is one such technology with potential applications across a wide range of sectors with promised sustainability benefits. Over the past decade, the field in the UK has been subject to active policy intervention and support. This article explores the role played by the sustainability agenda in policy debates and the policy mix in support of this emerging field in the UK. Through an exploratory case study approach, I describe the processes through which synthetic biology came to be the subject of policy intervention where wider sustainability goals were situated as subsidiary to the commercialisation agenda. Analysis of the policy mix reveals how this has fed through into a supply-side bias with limited consideration given to actively create or stimulate demand for *sustainable* synthetic biology applications. These features, combined with limited capacity for anticipation and monitoring, are likely to limit the capacity of the field to drive socio-technical transformation due to a lack of attention to policy coordination, reflexivity, and directionality.

1 Introduction

There is growing policy interest in the role that science, technology, and innovation (STI) can play in providing solutions to the sustainability challenges faced by society (Cervantes & Hong, 2018; Langhelle et al., 2019; UNCTAD, 2018). Yet, the magnitude and speed of change required alongside the multifaceted and contested nature of sustainable development render this challenge somewhat exceptional (Mowery et al., 2010).

Researchers have responded to this from a range of theoretical, conceptual, and methodological perspectives (Hansmeier et al., 2021). One pertinent avenue has been to draw on the literature that explores the processes through which innovation occurs and how technologies emerge and become embedded in society. This carries the hope of appropriating this understanding to (re)direct STI towards desirable ends and has led to the rapid rise of the field of study termed *sustainability transitions* (Köhler et al., 2019). These developments necessitate new framings and approaches to STI policy in order to incorporate the goal of systemic transformation (Schot & Steinmueller, 2018).

The emerging technological paradigm of synthetic biology (also known as engineering biology) is one such area of STI policy interest that has considerable relevance to sustainable development (French, 2019). The applications it enables promise broad impacts across a wide range of sectors, enabling a transition to more sustainable bio-based production (Bueso & Tangney, 2017; EBRC, 2019). It is in part these sustainability benefits that have been powerful in legitimising public and private support. Yet, these benefits are also contested (ETC Group, 2010) and involve difficult trade-offs (Matthews, Cizauskas, et al., 2019).

Synthetic biology has now been the subject of active policy intervention for over a decade across several countries, particularly from national governments (Shapira et al., 2017). In the UK, a considerable programme of support was initiated in 2012 which aimed to nurture a cutting edge synthetic biology community with particular attention to supporting its commercialisation (Clarke & Kitney, 2016; SBRCCG, 2012). The programme was also been characterised by a focus on responsible research and innovation (RRI)¹ which seeks to promote anticipation, reflection, and action regarding the broader societal impacts and implication of STI (Macnaghten et al., 2016; Taylor & Woods, 2020).

This article seeks to understand the role that the sustainability agenda has played in the promotion of synthetic biology in the UK. I focus on how visions and expectations of

¹ RRI is often used interchangeably with responsible innovation (RI). While the distinctions between the two discourses have been explored by others (Owen & Pansera, 2019), in this paper I primarily use the term RRI to refer to both overlapping discourses.

improved sustainability have been mobilised within policy processes and how these have been rationalised within the policy strategy and instrument mix. This analysis is guided by insights from the science and technology studies (STS) (Borup et al., 2006), political science (Kern & Rogge, 2018; Kingdon, 1984), and policy mix (Flanagan et al., 2011; Rogge & Reichardt, 2016) literatures. Additionally, I draw on the transformational innovation policy (TIP) literature to explore to what extent the approach to synthetic biology in the UK has addressed transformation failures (Schot & Steinmueller, 2018; Weber & Rohracher, 2012). Together, these literatures provide a framework to guide and structure the analysis, as elaborated in Section 2 (Figure 1).

Applying this framework to the empirical case of synthetic biology in the UK, I integrate data from a range of sources to enable process tracing (George & Bennett, 2004), as described in Section 3. The findings of this investigation, reported in Section 4, identify the significant discursive role played by the sustainability agenda and promises of social and environmental value creation in helping to open up and exploit the policy window in 2012. However, this broader vision, which largely became encapsulated within the concept of RRI, was not reconciled with the dominant policy imperatives of commercialisation and financial return. This, alongside an assumption of sustainability, led to a lack of consideration in the resulting policy strategy and instrument mix concerning how to actively create and stimulate demand for *sustainable* synthetic biology applications. As a result, I argue that the approach to synthetic biology in the UK demonstrates transformational failures in terms of reflexivity, policy coordination, and directionality (Weber & Rohracher, 2012).

2 Literature review and analytical framework

2.1 Emerging technologies, hype, and policy

Emerging technological paradigms are often accompanied by promissory visions and hype that play important roles in enabling and shaping their early development (Grunwald, 2018; Pollock & Williams, 2010). This *promissory rhetoric* put forward by technology advocates can shape the expectations of policy-makers concerning what particular technologies are anticipated to achieve (Borup et al., 2006; Schyfter & Calvert, 2015). Such expectations can lead to the commitment of resources to a field and shape new institutional arrangements, thus becoming performative self-fulfilling prophecies (Petersen & Krisjansen, 2015).

Recently, there has been a growing prevalence of visions concerning how STI can tackle societal grand challenges such as Net Zero and the Sustainable Development Goals (SDGs) (UNCTAD, 2018). This *Grand Challenge* agenda has led to expectations of emerging technologies delivering societal as well as economic benefits (von Schomberg, 2013). In

order to legitimise a technological trajectory through its association with broad-brush societal goals such as sustainability, the link has to be articulated by breaking down and specifying the goal and explaining how the technologies in question can contribute (van Lente & van Til, 2008). However, in time this association can become black-boxed such that the link between a technology and sustainability no longer requires further justification (Latour, 1987).

Expectations are negotiated in a diverse and contested space as part of messy and path-dependent policy processes (Brown & Michael, 2003; Lindblom, 1959). Within these processes, ambiguity is often manifest (Ackrill et al., 2013). The deliberate use of ambiguity can be an important strategy for advocates to achieve alignment in complex political environments (Edler & James, 2015; Leitch & Davenport, 2007). Under these conditions generally agreeable yet vague and malleable concepts such as sustainability can act as *boundary objects*, helping to foster high-level agreement while tolerating a great deal of ambiguity regarding the specifics (Brand & Jax, 2007; Star, 2010).

To help us understand this messy process we can draw from the policy studies literature. In particular, Kingdon's three streams framework describes how, while the policy stream may evolve with different ideas and propositions in a path-dependent manner, *policy windows* open up only when the perceived problem, policy solution, and the appropriate political backdrop intersect and opportunities for intervention arise (Kingdon, 1984). It has been observed that the policy solution often emerges first followed by a search for an appropriate problem to provide a rationale (Kern & Rogge, 2018). Alignment of the streams within policy windows can be partially articulated by policy entrepreneurs: organisations, actors, or teams who are willing to invest "time, energy, reputation, and sometimes money" (Kingdon, 1984, p. 122) in search of policy change. Advocates for a technology, who often put forward the promissory visions of the future in order to establish positive expectations amongst policy-makers, could be considered key policy entrepreneurs for emerging technologies (Rip, 2006). Depending on the outcome of these processes, a policy window may open up and policy intervention may result.

2.2 Policy mixes for innovation

Policy intervention typically takes place through the design and implementation of policy instruments. However, it is important not to consider policies in isolation but rather as part of a mix of instruments that interact over space and time (Flanagan et al., 2011). Furthermore, the nature of the contemporary challenges that STI policies seek to tackle, tending to be complex and systemic, requires concerted action through a mix of policies (Edmondson et al., 2018). Such policy mixes can be realised through packages of *de novo* policies or by

130 'patching' existing policy elements (Howlett & Rayner, 2013). Resulting mixes can be
131 delineated through a top-down approach, starting from the policy-making processes
132 previously discussed, or from a bottom-up approach, starting from a particular impact
133 domain being studied (Ossenbrink et al., 2019). According to Rogge & Reichardt (2016),
134 policy elements can be broken down into the objectives and plans that underpin the
135 overarching policy strategy as well as the instrument mix itself, each with associated goals,
136 type, purpose, and design features. Collectively, a given policy mix can also be analysed
137 with respect to certain characteristics, notably: "...the consistency of elements, the
138 coherence of processes, as well as the credibility and comprehensiveness of a policy mix"
139 (ibid., pp. 1622-3).

140 There are many different rationales for intervening in innovation systems and a
141 corresponding diversity of instruments that can be employed.² One distinction commonly
142 made is between supply-side and demand-side oriented instruments where a historic
143 tendency to neglect the role of demand-side intervention has been noted (see Edler &
144 Georghiou, 2007). Rogge & Reichardt (2016) divide instruments up further according to their
145 purpose – technology push (i.e. supply-side), demand-pull, or systemic (supply- and
146 demand-side) – and their type – economic instruments (e.g. R&D funding, tax incentives,
147 public procurement), regulation (e.g. standards, environmental regulations, IP protection),
148 and information (e.g. training, networking events, foresight). While these classification
149 systems can help to make sense of the wide range of instruments employed, it is also
150 important not to consider them as 'tools from a toolbox' because policies are subject to
151 considerable interpretive flexibility depending on the context in which they are applied
152 (Flanagan & Uyarra, 2016).

153 Finally, when analysing a given policy mix we must also avoid an idealised view of how
154 policy mixes can be designed and coordinated, and of policy-making and policy
155 implementation processes more broadly (Flanagan et al., 2011). New policy instruments and
156 mixes are applied on top of and constrained by the existing policy mix and institutional
157 context and thus policy action is necessarily incremental (Lindblom, 1959). The effect of
158 specific instruments will also be a function of interactions that can take place across time
159 and space (policy, governance, and geographical space) (Flanagan et al., 2011). This
160 complexity has been recognised in *broad* policy mix conceptualisations which emphasise the
161 policy process as an inseparable part of the policy mix alongside the policy instruments

² See Edler & Fagerberg (2017) for an overview of the rationales for innovation policy intervention and a taxonomy of innovation policy instruments.

themselves while also considering the interactions between policies (Flanagan et al., 2011; Rogge & Reichardt, 2016).

2.3 New goals for innovation policy

In the context of pressing grand challenges such as climate change and the need for more sustainable development, there has been a trend towards a more mission-orientated approach to innovation policy, considering how innovation systems can be mobilised to directly tackle these grand challenges (Hekkert et al., 2020; Mazzucato, 2016). In line with this agenda, a growing volume of research has explored how to achieve the radical transformation of socio-technical systems towards more sustainable modes of operation, under the broad grouping of sustainability transitions research (Köhler et al., 2019).

These developments in our understanding of the role of innovation systems introduce new requirements for innovation policy and have led to its reframing for transformational change (Schot & Steinmueller, 2018). This framing marks a considerable departure from previous framings. In the immediate post-war era, the innovation for growth perspective became entrenched, underpinned by the now much-critiqued linear model (Godin, 2006; Kline & Rosenberg, 1986; Nightingale & Coad, 2020). In this context, the primary role of the state was to address market failures by funding basic research to generate new discoveries and drive progress (Bush, 1945). Subsequently, the systems of innovation approach emphasised the significance of interactions, networks, institutions, entrepreneurship, and absorptive capacity in determining the outcomes of innovation (Freeman, 1995; Lundvall, 1992). Increasingly, both of these frames are considered insufficient for nurturing the urgent transformational change now required by society (Schot & Steinmueller, 2018). In the new, transformational innovation policy (TIP) framing, the function of innovation policy instruments is no longer purely to improve innovative capacity but to address “transformational failures” which prevent the alignment of STI with societal and environmental goals and needs (Weber & Rohracher, 2012). Here, I focus on failures in terms of *policy coordination*, *reflexivity*, and *directionality* (ibid.).

As sustainability transitions require concerted changes in multiple areas, and given the deeply embedded nature of present socio-technical systems (Schot & Kanger, 2018), it is generally accepted that *policy coordination* across STI, sectoral, and cross-cutting policies is required (Weber & Rohracher, 2012). Therefore, policies need to go beyond simply supporting and accelerating niche innovations through instruments such as R&D funding and the provision of finance (Kanger et al., 2020). Interventions such as regulation and the withdrawal of subsidies can be used to destabilise incumbents (Kivimaa & Kern, 2016; Turnheim & Geels, 2012) while further demand-side interventions such as the use of public

197 procurement can also help to stimulate demand in application sectors (Edler & Georghiou,
198 2007). Such policies can also play important roles in articulating broad societal challenges
199 such as sustainable development into more concrete demand for innovations (Boon & Edler,
200 2018).

201 While a highly planned approach to governing transitions might be desirable, exerting control
202 on emerging technological paradigms is also acknowledged to be exceedingly difficult if not
203 inherently problematic due to inevitable uncertainty over its development and impact
204 (Collingridge, 1980; Edmondson et al., 2018; Mowery et al., 2010). More fundamentally,
205 there are many different potential pathways and end-points for transitions, within which there
206 may be differing roles for innovation and technology (Scoones, 2016). Therefore, progress
207 towards desired transformations cannot be taken for granted. Instead, there is a need to
208 embed *reflexivity* by putting in place systems for “continuous monitoring and anticipation”
209 (Weber & Rohracher, 2012, p. 1044) such that governance and policy can be appropriately
210 adaptive. The RRI agenda could be considered an attempt to embed these capacities within
211 innovation systems (Stilgoe et al., 2013).

212 Finally, a critical feature of these new framings of innovation policy is its more explicit
213 attention to *directionality*. In previous systems of innovation framings, the target of policy
214 intervention was a well-functioning and competitive innovation system with less attention to
215 the direction of change³ (Diercks et al., 2019). Conversely, in the TIP framing, there is a
216 normative expectation that innovation should be actively guided towards realising more
217 sustainable socio-technical systems (ibid.). In line with this, shared visions and expectations
218 need to be established concerning how innovation can address such broader sustainability
219 challenges and needs (Weber & Rohracher, 2012). Within this framing, STI no longer has an
220 intrinsic benefit and instead must be judged by its ability to actively create value in a broad
221 sense (Schot & Steinmueller, 2018), necessitating a focus on social and environmental value
222 creation beyond the traditional focus on financial return (Dyck & Silvestre, 2018). The deeply
223 embedded nature of the present socio-technical systems, reinforced by repeated surges of
224 technological development since the industrial revolution, makes it particularly challenging to
225 shift towards this new, more sustainable directionality with a broader conception of value
226 (Schot & Kanger, 2018). It also means that, if emerging technologies are treated in isolation
227 without explicit attention to their directionality and the kinds of value they create within the
228 wider economy, they risk being redirected in unsustainable directions by the inertia of
229 incumbent regimes (ibid.).

³ Although this type of intervention arguably has an implicit directionality towards more innovation, more technology, and more economic growth.

2.4 Analytical framework and research question

The literature discussed above can be organised into a single cohesive analytical framework for this study (Figure 1). Policy processes are understood by drawing on insights from both the policy studies and STS literatures (Borup et al., 2006; Kingdon, 1984). The broad policy mix framework put forward by Rogge and Reichardt (2016), is used to complete the policy sub-system, guiding a structured and holistic analysis of policy intervention. Finally, the process and outcomes of socio-technical change require explicit consideration, drawing on the TIP and sustainability transitions literatures, with particular focus on how transformational failures have or haven't been addressed (Weber & Rohracher, 2012). This framework enables the integrated consideration of political processes, policy mixes, and socio-technical change along with their interaction, as has been called for by others (see Edmondson et al., 2018; Meadowcroft, 2011).

Guided by the analytical framework, this study explores the research question of what role sustainability has played in the promotion of a particular emerging technological paradigm (synthetic biology) within a particular national context (the UK). The analysis is particularly focussed on two aspects, represented by the two arrows in Figure 1. The first relates to the role played by competing promises and expectations (including that of sustainability) in opening up and exploiting a policy window and how this has translated into the policy strategy and policy mix. The second looks beyond the policy sub-system to probe how the policy mix has been implemented in practice and to what extent this has addressed transformation failures in accordance with the expectations and promises established during the policy process.

Figure 1: The analytical framework for this study. (Source: Author's synthesis drawing on Borup et al., 2006; Kingdon, 1984; Rogge & Reichardt, 2016; Weber & Rohracher, 2012).

3 Research approach

3.1 Methodology

To operationalise the analytical framework described above, this exploratory case study employs process tracing to chart the causal dynamics which have produced particular outcomes for synthetic biology in the UK (George & Bennett, 2004; Streb, 2010; Yin, 2018). This approach focusses on analysing the “empirical fingerprints” of hypothesised underlying mechanisms and relies on the gathering of large amounts of data from a range of sources to build up a comprehensive picture of a complex process (Beach, 2017).

Two main sources of data were used. Firstly, documentary evidence was gathered from a wide range of sources including policy documents (e.g. roadmaps and strategies), meeting minutes, websites, and news articles. Documentary evidence typically relates to the outcome of policy-making processes and so can give the impression of consensus amongst actors, hiding the messy underlying policy processes (Tansey, 2007). To corroborate findings, fill in gaps, and allow more detailed probing of the processes and rationales that led to specific policy events, semi-structured interviews were undertaken with influential players in the UK synthetic biology landscape. Non-probability purposive sampling was used to select research participants (ibid.). Interviewees were selected based on their involvement in key policy processes such as positions on committees or within organisations. Semi-structured interviews were then conducted based on an interview guide (Appendix A). It was critical to be mindful of some of the potential pitfalls of elite interviewing, particularly the fact that interviewees inevitably have their own agendas – as Berry (2002) puts it: “...subjects have a purpose in the interview too: they have something they want to say” (p. 680). By combining analysis of diverse documentary evidence with targeted interviews, this methodological approach enabled triangulation, helping to alleviate the limitations that both these data sources pose when used in isolation.

Due to the COVID-19 pandemic, all interviews were carried out by video call. Nine interviews took place between April and June 2020 (see Table S1). After each interview, interviewees were sent a short vignette summarising the discussion allowing them to add additional details or correct any misunderstandings. Documentary and interview data were then collated and the Nvivo software was used for thematic qualitative coding, following best practices in interpretive social science research (Mason, 2017; Nowell et al., 2017; QSR International, 2018). Initially, a set of deductive codes were employed to group the documentary data according to the overall analytical framework presented above. As researcher familiarity with the data grew, sub-codes of a more inductive nature were

developed. Data analysis proceeded through several iterations between the literature, data analysis, and summarising. See Table S2 for a summary of data sources, research sub-questions, and resulting themes across the three dimensions.

Finally, to complement the thematic coding described above, tables were produced summarising the key policy documents (Table S3) and the policies identified (Tables 1 and S4). These tables provided evidence to underpin Sections 4.1, 4.2, and 4.3 of the findings. In support of the findings reported in Section 4.4, further analysis and coding of specific subsets of the documentary evidence was undertaken (Tables S5-7). A coding manual for each of the Tables 1 and S3-7 is provided in Appendix B.

3.2 Empirical case – synthetic biology in the UK

The empirical setting for this study was the emerging field of synthetic biology in the UK. Synthetic biology⁴ brings together advances in molecular biology and genomics with engineering principles and computational approaches for the development of real-world applications. It can be defined as follows: “Synthetic biology aims to design and engineer biologically based parts, novel devices and systems as well as redesigning existing, natural biological systems” (RAE, 2009, p. 13). In attempting to bridge many well-established fields, it has somewhat fuzzy boundaries. Indeed, some would not consider it a field *per se*, instead viewing it as a particular way of approaching biological research which has implications for a broad range of fields and application domains. In particular, it has implications for the application domains of industrial biotechnology, health and medicine, food and agriculture, environmental biotechnology, and energy (EBRC, 2019). In this article, it is viewed as an enabling set of emerging technologies that promise to facilitate the broader spread of biotechnology into new fields and areas not previously accessible, thus having broad societal relevance (Bueso & Tangney, 2017).

The first reports of the ‘repressilator’ and toggle-switch at the turn of the new millennium are often cited as the starting point for the field as the first examples of “genetic circuits that had been engineered to carry out designed functions” (Cameron et al., 2014, p. 382). It is this application of an engineering approach to design, create, and tune biological systems that sits at the core of synthetic biology. Since then, synthetic biology has attracted both scientific and policy interest (Figure 2). 2004 saw the first international conference, SB1.0, take place at MIT as well as the first International Genetically Engineered Machine (iGEM) competition

⁴ Recently, the term Engineering Biology has been increasingly used to describe the field, in particular when it intersects with the industrial domains where synthetic biology enables applications, such as industrial biotechnology. Here, the use of the original synthetic biology description is retained but the two terms are treated as synonymous.

for university students (ibid.). It is around this time that the volume of academic articles in the field started to increase (Shapira et al., 2017). The earliest support for the field was most prevalent from US Government sources and funders such as NSF and NIH have continued to dominate the funding landscape (ibid.). Other key funding sources include the national governments of China, Japan, Canada, as well as various European nations and the European Union (ibid.). The UK government has taken an active and fairly interventionist approach and throughout the 2010s put in place a range of policy instruments to support the establishment and development of the field (Clarke & Kitney, 2016).

This study uses the empirical case of synthetic biology in the UK⁵ to operationalise the analytical framework described in Section 2.4. The reasoning behind choosing to study this case at this time is threefold. Firstly, it represents a platform technology with potentially broad impact, including in many areas of relevance to the SDGs (French, 2019). Therefore, in terms of the policy mix and sustainability transitions agenda, it provides an opportunity to build the evidence base beyond the energy sector from where the majority of empirical evidence and policy success stories derive (Kern et al., 2019). Secondly, it is an emerging technology where there has been debate concerning its promise and potential while its implications for the environment and society remain contentious. It is instructive to understand whether and how sustainability goals are incorporated into policy design and implementation under such circumstances. Finally, the timing and geographical focus of this study are pertinent in that many of the programmes that kicked off in the early 2010s are coming to an end or entering a transition period. This has triggered a period of reflection within the synthetic biology community concerning what has been achieved so far and where to go next (e.g. RAE, 2019; SBLC, 2019).

4 Findings

This section presents the findings of the study. It is structured in three sections which correspond to the three interlocking dimensions of the analytical framework elaborated in Section 2.4 and Figure 1. The findings were derived from the analysis as described in Section 3.1 and summarised in Table S2.

⁵ The boundaries of the UK synthetic biology field are inevitably fluid, with research activity and companies spanning national boundaries and many international initiatives and collaborations. However, national contexts remain relevant and it was necessary to draw boundaries in order to enable rich and in-depth analysis within the empirical case.

4.1 Diverse expectations for an emerging field

It is possible from the data collected in this study to delineate some of the key visions and rationales put forward to promote the field and how these differ between actors. Advocates for the field⁶ justified policy support for synthetic biology by pitching it as an exciting platform technology that could be highly disruptive in a range of sectors. They described it as an area where the UK could harness its strong research base to create high-tech jobs and economic growth through the increased commercialisation of research outputs. This was sometimes accompanied by the warning that without action the UK risked falling behind as other countries capitalise on these scientific developments. Together, these visions presented a persuasive case to policy-makers for support and are evident in many of the key policy reports which such advocates have often played a key role in writing or steering (Table S3).

Accompanying this economic vision was a broader one, focussed on how synthetic biology could provide solutions to grand challenges, particularly that of creating a more sustainable society. Indeed, many of the proposed application areas map to the SDGs (French, 2019). While this sustainability promise has been put forward to some extent from the start (e.g. Endy, 2005), it became more overt in recent years, as sustainability concerns, and particularly agendas around Net Zero and plastics, have grown in prominence.⁷ References to sustainability benefits have often been broad and ambiguous although there was a noticeable focus on the environmental rather than social benefits of synthetic biology. Most prominent was the promise of weaning society from its dependence on fossil fuels by providing alternative bio-based routes to chemicals, energy carriers, and materials, potentially making use of waste carbon sources.⁸ Many advocates for the field saw the sustainability agenda as a means to communicate the benefits of this technology and provide a compelling story for why it should be supported. As a result, the adjective *sustainable* has often been used when describing synthetic biology, for example in delivering “sustainable solutions” or “sustainable materials”. In some cases, bio-based technologies were presented as intrinsically sustainable. The link had become black-boxed.

⁶ By “advocates for the field” I mean individuals who commit often considerable time, resources, and reputation to publicly support and articulate the benefits of the technology.

⁷ A recent supplement in the *New Statesman* carries articles from many key advocates very clearly putting the sustainability argument ahead of the economic one (New Statesman, 2020).

⁸ Health and Medicine also represents a key application area and has a clear link to the SDGs (Particularly goal 3: *Good Health and Well-Being*). Yet, claims of sustainability for the field have tended to focus on environmental aspects and the link between improving health outcomes and sustainable development was rarely articulated. For this reason, they are not the focus of the analysis presented here.

Not all visions of synthetic biology's impact were quite so positive. Early-on, civil-society organisations tabled some stark warnings concerning where the field appeared to be heading (e.g. ETC Group, 2007). Three central issues were raised: a) that the field was overhyped and the claimed benefits for society lacked evidence; b) that the ethical, socioeconomic, and environmental risks were manifest and poorly understood; and c) that regulation was essential, self-regulation dangerous, and that wider society should play a key role in determining what is permitted. This debate was seen by some as a reigniting of the "GM debate", something many advocates feared (Marris, 2015). Interestingly, these alternative visions were also largely sustainability-focussed, but often with a broader definition, a *vulnerable nature* worldview, and greater attention to socioeconomic issues (Asveld et al., 2014).

Meanwhile, social scientists, principally working in the fields of STS and innovation studies, also highlighted some of the risks and challenges posed by synthetic biology concerning biosafety and biosecurity, ethics, global justice, patenting and monopolies, and ethical dilemmas around the creation of artificial life (Balmer & Martin, 2008). Building on considerable engagement in the emergence of the nanotechnology paradigm, researchers continued to emphasise the uncertainties, unknowns, and unintended consequences that typify emerging technologies and the need for the 'opening up' of appraisal and governance to broader perspectives and values (Ribeiro et al., 2017; Stirling, 2008). They proposed the use of more responsive, iterative, and participatory governance models such as RRI for emerging technologies like synthetic biology (Marris & Calvert, 2020; Stilgoe et al., 2013; Wiek et al., 2012).

4.2 Choosing synthetic biology

With these diverse visions, promises, and expectations now elaborated, I will explore how synthetic biology came to be chosen for policy intervention. Policy change necessitates the alignment of a recognised problem with a recognised solution at a politically appropriate time (Kingdon, 1984). The 2010 UK general election resulted in a coalition government, led by the Conservative party, for which two notable policy priorities were evident - to stimulate and maintain economic growth in the aftermath of the financial crash, and to reduce the public sector net deficit.⁹ Therefore, there was a desire to play to the UK's strengths, one of which has long been considered the UK's research base. However, there has also been a

⁹ The coalition's *programme for government* stated: "We recognise that deficit reduction, and continuing to ensure economic recovery, is the most urgent issue facing Britain." (HM Government, 2010, p. 15)

perception that while the UK is good at research, it is bad at commercialising it.¹⁰ In this new government, David Willetts (now The Lord Willetts) was made Minister of State for Universities and Science at the Department for Business, Innovation and Skills (BIS).¹¹ Willetts, together with the Liberal Democrat Business Secretary Vince Cable, supported an interventionist strategy of targeted support for high-tech innovations to stimulate economic growth.¹²

Meanwhile, synthetic biology by the early 2010s had received a steady flow of funding from the research councils, helping to establish the beginnings of a synthetic biology community in the UK (Figure 2; Shapira et al., 2017). The 2009 Royal Academic of Engineering (RAE) report highlighted synthetic biology as a field where the UK was already strong and presented opportunities for wealth and job generation alongside tackling global challenges (RAE, 2009). The report also emphasised the urgent need to develop a strategy for synthetic biology. Consequently, this emerging field found itself well-positioned to capitalise on the policy window which consisted of a policy problem in the need to drive economic growth while making efficient use of limited public funds, a promising solution offered by synthetic biology, and a political environment that supported interventionist innovation policies.

Around the same time, synthetic biology had begun to appear as a topic in Government horizon-scanning efforts, notably the Technology and Innovation Futures reports (see Government Office for Science, 2010, 2012).¹³ A roundtable discussion at BIS hosted by David Willetts in the autumn of 2011 led to the establishment in November 2011 of a working group tasked with developing a roadmap for synthetic biology in the UK. The Roadmap was duly published, under a tight schedule, in July of 2012 (Marris & Calvert, 2020). As well as

¹⁰ For example, an inquiry on this issue by the House of Commons Science and Technology Committee House was launched in 2011 with the statement: “A key recurring issue that has been raised in the Science and Technology Committee’s previous inquiries is the difficulty of translating research into commercial application...”. However, whether or not this widespread view is justified has been the subject of debate (e.g. see Mazzucato, 2013, pp. 52-3).

¹¹ This department is now called the department for Business Energy and Industrial Strategy (BEIS) after the merger in 2016 of BIS with the Department for Energy and Climate Change (DECC).

¹² This approach accompanied political discussions concerning the need for a dedicated Industrial Strategy, which did eventually become a reality under the May government (HM Government, 2017). Vince Cable set out in a 2012 letter to the then Prime Minister David Cameron and Deputy Prime Minister Nick Clegg his view that “Market forces are insufficient for creating the long-term industrial capacities we need” and that “...the Government can show more leadership in identifying and supporting key technologies. We have a fantastic scientific tradition in this country, and technology leadership must drive economic activity in the future.” (Cable, 2012).

¹³ These Foresight reports would inspire the *Eight Great Technologies*, of which Synthetic Biology was one (Willetts, 2013).

touting the considerable benefits of the technology, it set out a series of recommendations centred concerning how to support the development of synthetic biology in the UK (SBRCG, 2012). These recommendations were positively received and several policy initiatives were subsequently announced in alignment with the roadmap recommendations (Willetts, 2012). Of course, public documents often mask the actions that occur ‘behind the scenes’ to enable the exploitation of a policy window in which there is a key role played by policy entrepreneurs. In this case, two key individuals can be identified. Willetts, as already discussed, was receptive to the case for policy intervention in support of emerging technologies like synthetic biology, and willing to make the case for it both within and outside government. Meanwhile, Lionel Clarke¹⁴ led the development of the roadmap, playing a key role in articulating a compelling argument for support and aligning this with the priorities of the government of the day.

Figure 2: The emergence of the synthetic biology field. (A) Annual Web of Science indexed publications mentioning “synthetic biology” in their title, abstract, or keywords. (B) Overview timeline of key events, reports, and initiatives referred to in the text.

¹⁴ At the time, Clarke was a Global Strategic Programme Manager for Shell Global Solutions.

Synthetic biology attracted controversy and debate from almost the moment it emerged as a concept. Indeed, the complex ethical, legal, and social aspects (ELSA) of the technology were recognised by its advocates and one response was to actively engage social scientists as contributors to the policy development process (Calvert & Martin, 2009). A key example of this was the act of inviting social scientists, often from STS traditions, to sit on the working group for key policy reports, notably the 2009 RAE report and the 2012 roadmap (RAE, 2009; SBRCG, 2012). STS research provides a wealth of insights that can inform the policy processes such as by outlining how hype, promises, and expectations can become self-fulfilling prophecies (Borup et al., 2006), and how present policy and governance approaches often fail to acknowledge the value judgements embedded in decision-making around STI and tend to lead to the closing down of debate (Smallman, 2019; Stirling, 2008; Wilsdon & Willis, 2004). This often quite critical stance can create tensions. STS scholars have not always had a receptive response to their critiques and have sometimes found that their insights and text have been utilised in a manner distinct from what they intended (Marris & Calvert, 2020). The implications of this are discussed in subsequent sections.

The role of sustainability in this melting pot of visions and ideas can be difficult to track. The promise of tackling sustainability challenges seems to have helped to generate enthusiasm for synthetic biology alongside promises of economic growth and responsible innovation. In line with this, many of the influential policy reports, particularly those focussed on industrial biotechnology¹⁵, referred to sustainability as a key reason to fund the field (Table S3). Although the 2012 roadmap made only occasional mention of sustainability, on page seven it is highlighted as one of the key global needs which synthetic biology can address. Meanwhile, synthetic biology to “heal us, feed us, and fuel us” became a popular tagline for politicians around 2012. Indeed, it appears to be the way in which an opportunity to drive high-tech economic growth seemingly overlapped with delivering solutions to global sustainability and health challenges that made synthetic biology such a compelling investment case for the UK Government.¹⁶

4.3 Policy intervention in support of synthetic biology

The successful exploitation of the c.2012 policy window by synthetic biology’s advocates resulted in considerable policy support in the UK (Figure 2B; Table 1). This section will

¹⁵ Industrial biotechnology represents one of the major application areas for synthetic biology. Reports focussed on industrial biotechnology are included in this analysis due to their tight overlap with the synthetic biology ecosystem in the UK.

¹⁶ In a 2012 speech, Willets stated: “Synthetic biology could provide solutions to many of humanity’s most pressing issues and at the same time presents significant growth opportunities”.

examine the resulting policy mix with respect to the four characteristics outlined by Rogge & Reichardt (2016): *consistency, coherence, comprehensiveness, and credibility*.

Considering first the overall policy strategy, this needs to be *consistent* in that the objectives of policy intervention should be complementary, drawing out synergies between them (Rogge & Reichardt, 2016). The UK policy strategy was largely outlined in two policy documents: the 2012 Synthetic Biology Roadmap and the 2016 strategic plan (SBLC, 2016; SBRCG, 2012). The roadmap set out a vision for a UK synthetic biology community which was: i) “economically vibrant, diverse and sustainable”, ii) “cutting edge”, and iii) “of clear public benefit... addressing global societal and environmental challenges” (SBRCG, 2012, p. 4). In terms of the first aspect, this was clearly into a policy objective in the subsequent strategic plan with the target of achieving “a £10bn UK synthetic biology market by 2030” (SBLC, 2016, p. 2). This would appear to be synergistic with the second vision – of a “cutting edge” synthetic biology community in the UK as both imply policy interventions which seek to address market and system failures in order to support the development, scale-up, and commercialisation of synthetic biology applications. Correspondingly, the recommendation of the roadmap centred on supply-side support for research, innovation, and translation; training and skills development; networking and information brokerage services; and establishing a leadership council to give strategic direction and coordination. An instrument mix was subsequently put in place which was largely *consistent* with these recommendations, as will be discussed.

The third vision, relating to being of “clear public benefit”, was more ambiguous. The concept of RRI was introduced into the roadmap by social scientists involved in its authorship, and the corresponding section of the roadmap explicitly sought to address how synthetic biology can be “demonstrably directed towards new products, processes and services that can bring clear public benefits” as well as “solutions to compelling problems” (SBRCG, 2012, p. 19). Yet, besides one mention of RRI in the subsequent recommendations of the roadmap, there was comparatively limited attention to how “clear public benefit” was to be achieved. This *inconsistency* may reflect a lack of *coherence* in the policy processes that resulted in the critical 2012 roadmap. Social scientists on the steering group successfully introduced the concept of RRI into the roadmap, reframed the focus on public acceptability in terms of generating public benefit, and introduced phrases such as “diverse and sustainable” (Marris & Calvert, 2020). However, they were unable to question the dominant focus on economic imperatives which meant that the underlying messages of RRI were not reconciled within a *coherent* policy strategy (ibid.). This would have required the policy strategy and instrument mix to be designed in a way that took greater account of uncertainty concerning often assumed benefits such as sustainability by embedding mechanisms for anticipation,

inclusion, reflexivity, and responsiveness (Stilgoe et al., 2013). Instead, positioned as subservient to the dominant economic growth agenda, “RRI was interpreted as a means to smooth this path” (Marris & Calvert, 2020, p. 18).

Nonetheless, the characteristics identified above in the policy processes and policy strategy fed through clearly into a relatively *comprehensive* instrument mix (Tables 1 and S4), which put into practice the recommendations laid out in the 2012 roadmap and focussed on building the research base and promoting commercialisation. At the core of this was the BBSRC’s *Synthetic Biology for Growth Programme*¹⁷ which represented over £100 million of direct support for research, infrastructure, training, and venture capital. By 2016, total public sector investment in synthetic biology was estimated at over £300 million¹⁸ once all the various funding routes are taken into account (SBLC, 2016).

Consistent with the recommendations of the roadmap, there was a noticeable focus on economic instruments with the purpose of technology push (Table 1; Figure 3A). These policies primarily addressed the market failure rationale for STI policy intervention¹⁹, investing in areas that the market tends to underinvest in due to knowledge spill-overs and positive externalities (Weber & Rohracher, 2012). A large proportion of the allocated funding (~£70 million) was channelled into the establishment of six dedicated synthetic biology research centres (SBRCs) in 2013 and 2014. £18 million was also invested over two rounds in growing the UK’s DNA synthesis capacity and a centre for doctoral training in synthetic biology was established in 2014. Meanwhile, acknowledging that seed funding for high-tech start-ups can be difficult to come by, the BBSRC allocated £10 million in 2013 to a seed fund targeting synthetic biology start-ups which could allocate up to £1 million to each company. There have also been several rounds of industry-focussed R&D funding²⁰ while the industrial

¹⁷ Prior to this programme, synthetic biology had already been receiving government funding to support R&D and networking (SBRCG, 2012). Seven networks in synthetic biology were funded by UK Research Councils in 2007 and the first dedicated research centre for synthetic biology (CSynBi at Imperial College London) was established in 2009.

¹⁸ The total of policies listed in Table 1 comes to £245 million but this is just direct funding from the UK government and excludes funds from EU and Scottish Government sources.

¹⁹ In addition to this targeted policy support, UK research councils provide “responsive mode” funding which researchers can apply for at any time. The UK also has a range of more generalised, cross-cutting policies aimed at supporting research-intensive businesses. For example, R&D tax credits allow companies to claim tax relief in proportionate to their investment in R&D while from 2013 a Patent Box scheme was introduced with a lower corporation rate on profits from patented inventions.

²⁰ There were synthetic biology-specific calls from Technology Strategy Board (later Innovate UK) in 2012 (up to £6.5 million for feasibility studies), and 2013 (up to £3.8 million focussed on tools and services). The small business research initiative (SBRI) also had Synthetic Biology specific calls, notably two in 2014 and 2016 from DSTL focussing on defence applications.

527 biotechnology catalyst allocated £75 million between 2014 and 2016 before it was
528 discontinued.²¹

Policy initiative	Date	Value	Type	Purpose
<i>Synthetic biology research centres (SBRCs)</i>	2013 - present	£70M	• Economic instruments	• Technology push
<i>DNA synthesis infrastructure</i>	2014 - 2016	£18M	• Economic instruments	• Technology push • Systemic
<i>Centres for doctoral training</i>	2014 - present	£12M	• Information	• Technology push
<i>Innovation knowledge centre (SynbiCITE)</i>	2014 - present	£6M	• Information • Economic instruments	• Technology push • Systemic
<i>Future Biomanufacturing Research Hub (FBRH)</i>	2019-present	£10 million	• Economic instruments	• Technology push • Systemic
<i>Rainbow/UKI2S seed fund</i>	2013 - present	£10M	• Economic instruments	• Technology push
<i>Industrial biotechnology catalyst</i>	2014-2016	£75M	• Economic instruments	• Technology push • Systemic
<i>Networks in industrial biotechnology and bioenergy (NIBBs)</i>	2014-present	£29M	• Economic instruments • Information	• Technology push • Systemic
<i>Small Business Research Initiative</i>	2014 and 2016	£8M	• Economic instruments	• Technology push • Systemic
<i>Synthetic biology special interest group</i>	2012-2019	Unknown	• Information	• Systemic
<i>Synthetic biology leadership council</i>	2012 - present	Unknown	• Information	• Systemic
<i>BSI standards in synthetic biology</i>	2015	Unknown	• Regulation	• Demand pull
<i>Centre for Engineering Biology, Metrology and Standards</i>	2017 - present	£7M	• Regulation	• Demand pull

Table 1: A summary of key policy initiatives used to promote synthetic biology in the UK. Type and purpose classifications according to Rogge & Reichardt (2016). For an expanded version of this table see Table S4.

²¹ The Industrial Biotechnology Catalyst supported both researchers and businesses to work on translational projects with the intention of bridging the “valley of death” and accelerating commercialisation.

Signalling the *comprehensive* nature of the instrument mix, there was also a range of initiatives that sought to address systemic issues such as institutional, infrastructural, and network failures (Weber & Rohrer, 2012). The Knowledge Transfer Network (KTN) sought to coordinate and network the field, maintaining a Synthetic Biology Special Interest Group which was founded in 2012 and brought together over one thousand members. The KTN has also provided the secretariat for the Synthetic Biology Leadership Council (SBLC)²² which, co-chaired by a government minister and an industrialist, has sought to provide strategic oversight over activities in the UK. SynbiCITE, an Innovation Knowledge Centre, was established to invest in and generate co-funding for commercialisation projects, provide facilities and expert support for start-ups, host events and other networking opportunities, and deliver business and entrepreneurship training. Meanwhile, in the closely related area of industrial biotechnology, the BBSRC-funded networks in industrial biotechnology and bioenergy (NIBBs) were established to provide networking combined with proof of concept funding to “build capacity and capability in the UK supporting research and translation in sustainable, biologically based manufacturing” (BBSRC, 2019). The recently established Future Biomanufacturing Research Hub (FBRH) represents a further attempt to promote commercially relevant R&D and support the commercialisation of biomanufacturing.

Where the instrument mix has not been so *comprehensive* is in its relative consideration of the demand-side (Figure 3A). While some bias towards the supply-side might be expected given the early stage of development of the field, there has been a lack of policy measures that seek to stimulate demand in the potential application sectors for synthetic biology. There has, however, been some investment in developing standards²³ as well as some support for demand articulation through the promotion of collaborative R&D²⁴. The Small Business Research Initiative (SBRI) and the Industrial Biotechnology Catalyst also represent policies with some demand-side orientation²⁵ in that they support translation focussed on specific sectors. However, temporal *consistency* has been reported as a problem here, with

²² Note that the SBLC was recently renamed the Engineering Biology Leadership Council.

²³ Increased standardisation has been a central narrative in efforts to make biology into an engineering discipline, and in 2015 the British Standard Institute published standards for synthetic biology funded by Innovate UK. More recently in 2017, a £7 million Centre for Engineering Biology, Metrology and Standards was established as part of a partnership between the National Physical Laboratory and SynbiCITE.

²⁴ However, such policies involving collaborative R&D have still been largely focussed on technology push.

²⁵ There is some debate over whether these initiatives should be classified as supply- or demand-side (Edquist & Zabala-Iturriagagoitia, 2015). In this analysis, following the Rogge & Reichardt (2016) typology, they are annotated as “systemic” in Tables 1 and S4 based on their promotion of collaborative R&D.

intermittency in the funding of translational research, notably through the catalyst which was scrapped in 2016.

The relative importance and necessary balance of policy instruments within a given mix evolves over time (Cunningham et al., 2016; Flanagan et al., 2011). Therefore, the initial prioritisation of policies focussed on R&D, skills development, and establishing infrastructure may be justifiable providing that subsequent refinement of the mix introduces a greater focus on generating and articulating demand in application sectors.²⁶ The 2018 Bioeconomy Strategy promised to address this within the wider UK Industrial Strategy (HM Government, 2018). It integrated synthetic biology within a broader mission to expand the bioeconomy and sought to promote coordination across several sector-specific councils²⁷ as well as government departments and agencies. However, this is where *credibility* has been a potential issue as it was reported in interviews that this strategy appeared to lack high-level government buy-in, and therefore the corresponding coordinated policy intervention, has not been forthcoming. Relatedly, while David Willetts and subsequently George Freeman as Life Sciences minister represented important advocates for the field, since the latter politician left government in 2017²⁸ there has been less visible high-level backing for synthetic biology. More broadly, the Industrial Strategy under which the Bioeconomy Strategy was developed was scrapped in its present form in 2021.

4.4 Transformational failures in the UK synthetic biology programme

The previous section focussed on analysing the policy mix characteristics and how it was designed to address market and systemic failures in order to support the development and commercialisation of synthetic biology applications. This section will build on the issues identified there, with particular focus on how the policies have been applied in practice, to explain how the corresponding programme appears to have failed in addressing several transformational failures - namely in terms of *policy coordination*, *reflexivity*, and *directionality* (Weber & Rohrer, 2012).

²⁶ Policy options here include regulatory incentives and public procurement (Edler & Georgiou, 2007).

²⁷ Namely, the Industrial Biotechnology Leadership Forum, the Food and Drink Sector Council, the Chemistry Council, and the Medicines Manufacturing Industry Partnership.

²⁸ George Freeman ceased to be Minister for Life Sciences in July 2016 but remained as chair of the Prime Minister's Policy Board until November 2017.

Figure 3: A summary of results from analyses of the policy mix, company websites, and SBLC meeting minutes. (A) The characteristics of the policy mix according to purpose and type as a percentage of total policies (13) and total value of investment (£245M) (Tables 1 & S4); (C, D) the percentage of UK synthetic biology companies (n=54) (B) according to application domain and (C) demonstrating a commitment to sustainability and evidence of sustainability assessment or critical evaluation (Table S5); and (D) the percentage of SBLC meetings and of its Governance Sub-group where economic value, responsible innovation or social and ecological value have been discussed (Table S7). Note that for graphs A, B, and D the annotations are non-exclusive and so the figures will not add up to 100%.

In many senses, the UK synthetic biology programme has been a success. The UK remains a leading player in synthetic biology research, second only to the US in terms of publications²⁹ (Figure 2A; Shapira & Kwon, 2018). In terms of commercialisation, around 150 start-ups have reportedly been founded³⁰ and by one estimate over £1.8bn in private investment raised (SBLC, 2019). The BBSRC-funded seed fund has played a role in this by directly supporting synthetic biology start-ups and leveraging considerable co-investment from private investors (SQW, 2020). These start-ups are concentrated on platform and enabling technologies, which largely service other synthetic biology researchers and companies, as well as health and medicine (Figure 3B; Table S6). Health and medicine represents a domain where the UK economy has long-standing strengths, a strong market-pull, and there is a well-established commercialisation route for start-ups involving gaining IP protection followed by acquisition by large pharmaceutical companies (a so-called “exit”) (Clarke & Kitney, 2020).

However, as discussed in the previous section, while a policy mix to promote the development and scale-up of synthetic biology applications has been established, there has been a lack of *policy coordination* in terms of the broader sectoral and cross-cutting policies necessary for transformation (Weber & Rohrer, 2012). Correspondingly, there has been less success in several key application domains such as industrial biotechnology³¹ (Figure 3B) and relatively few start-ups have so far progressed to scale-up³². The previously discussed gap in the broader policy mix in terms of regulations, incentives, and public procurement initiatives that might stimulate demand for new bio-based technological solutions in application sectors may at least partially explain some of the scaling challenges faced in these application sectors. Significantly, it is also in these application sectors where the promised sustainability benefits of synthetic biology will or will not be realised.

Transformative change also calls for institutionalised *reflexivity* in order to anticipate, monitor, and be responsive in the face of uncertainty about the outcomes of innovation (Weber & Rohrer, 2012). In line with the 2012 roadmap, the RRI agenda has sought to embed reflexive capacity within the field, enabling distributed monitoring and governance.

²⁹ Albeit, Figure 2A suggests that the UK might have dropped below China in terms of publications in 2019.

³⁰ This was using a relatively broad definition and is a proprietary dataset. This study identified 54 UK-based companies currently operating (as of December 2020) working largely or exclusively in the domain of synthetic biology (see Appendix B).

³¹ For example, Green Biologics, a flagship UK company in the renewable chemicals space that raised £60 million of investment in 2015, closed its doors in 2019 after it struggled to compete with petrochemical-based incumbents.

³² See: <https://medium.com/@spchambers007/uk-synthetic-biology-survey-2019-48981e3695f0>

Some in the field have also considered these ongoing RRI activities to be the place where matters of sustainability should be considered. However, the subservient relationship of RRI to the dominant economic agenda and the often taken-for-granted nature of the sustainability benefits of synthetic biology, as described in the previous sections, seems to have shaped the way these policies were applied in practice.

The most notable example of RRI integration has been in the six SBRCs where ongoing evaluation required the integration of social science researchers and active consideration of ELSA³³ within the projects. A flexible approach was taken by funders concerning the kind of ELSA-work required and what kinds of social scientists should be involved. The position and power of RRI researchers within projects has also been ambiguous with their work tending to be separated from the core research and commercialisation efforts. Consequently, each of the centres has taken quite distinct approaches, from sociologists conducting ethnographic laboratory studies to attending science festivals and other science communication activities, to hosting an artist in residence (Table S6). Notably, while social scientists from a range of backgrounds have been involved, they did not tend to have backgrounds in sustainability. Furthermore, available assessment methodologies for monitoring the largely environmental sustainability promises made are mostly the domain of the natural sciences rather than social sciences. Consequently, the gathering of evidence concerning the sustainability implications of synthetic biology has been relatively limited within the research centres (Table S6).

A similar absence of monitoring was found in an analysis of UK synthetic biology company websites (Figure 3C; Table S5). This might be explained by the early stage of many of the companies – available monitoring approaches such as sustainability assessments are challenging to undertake responsibly at the early stages of technological development, and require considerable time, resources, and interdisciplinary expertise (Matthews, Stamford, et al., 2019). Another reason might have been the assumed and somewhat black-boxed link between “bio-based” and “sustainable”. That said, a subset of actors were seen to be acknowledging and grappling with sustainability trade-offs and some have commissioned or are undertaking sustainability assessments predominantly in the form of environment-focussed life-cycle assessment (LCA) (Figure 3C; Table S5). Such validation of sustainability claims was typically undertaken voluntarily, perhaps to avoid future accusations of greenwashing. Indeed, this study found no evidence of public-sector funders, investors, or regulators asking for or requiring evidence to support claims of improved sustainability.

³³ ELSA can be considered a major precursor to the RRI framework (see Zwart et al., 2014).

It is also notable the level at which this monitoring and anticipation has taken place, often within individual research initiatives or companies where there is relatively limited capacity to change the direction of travel, rather than being undertaken by those that set the overall strategic direction such as the SBLC and research funders.³⁴ An analysis of meeting minutes of the leadership council (the SBLC) and its governance sub-group revealed a focus on commercialisation and economic value creation, primarily at the main SBLC meetings (Figure 3D; Table S7). At the council's Governance sub-group, there was considerable discussion of proactive approaches to regulation and dealing with biosecurity issues, but an equivalent focus on social and environmental value *creation* was not evident.³⁵ This might be explained by two factors. Firstly, there were many other seemingly more pressing matters to discuss such as efforts to avoid the declaration of a moratorium on synthetic biology research and/or applications through the convention on biological diversity (CBD). Secondly, and more fundamentally, none of the long-term members of the SBLC or the sub-committee had particular expertise in sustainability.³⁶ Thus, matters of sustainability, particularly environmental aspects, seemed to fall through a gap in the middle of the two largely incongruent parallel streams. That is, the pursuit of economic value through the commercialisation of synthetic biology on the one side (primarily discussed at the main SBLC meetings), and on the other, attempts to deal with risks and potential controversy through proportionate regulation and RRI (primarily discussed at the governance sub-group).

Taken together, while there have been considerable efforts to embed distributed *reflexivity* at lower levels within the field, and some proactive attempts by researchers and companies to anticipate and monitor sustainability implications, this has not been integrated within the governance mechanisms that set the strategic direction. This greatly limits the capacity for responsiveness. Therefore, while individual actors may have gained the capacity to act reflexively, the wider innovation system has not. Furthermore, while some companies and researchers have sought to evaluate and evidence sustainability implications (with an environmental focus), these have been voluntarily and disparately undertaken, implying that

³⁴ Indeed, no one with expertise in this area (e.g. sustainability assessment) seems to have been a member of the leadership council or have been involved in steering any of the major policy reports.

³⁵ This is not to say that sustainability was not occasionally discussed or mentioned but that there appeared little strategic consideration of how to actively draw out the sustainability benefits, ensure that they are evidenced, or grapple with inevitable trade-offs.

³⁶ Two one-off exceptions to this were found: one meeting of the SBLC was attended by a member of the Government Office for Science Environment team and a Professor of Environmental Psychology attended one meeting of the Governance Sub-group. Civil servants in attendance from the Department for Environment, Food and Rural Affairs were generally focussed on GMO regulation as opposed to broader environmental sustainability aspects.

considerable knowledge gaps are likely to exist regarding the sustainability potential of the field.

A final consideration is that of *directionality*. The UK synthetic biology programme has focussed on developing an effective innovation ecosystem around this emerging technology to accelerate the development and commercialisation of the applications it promises. While a comprehensive policy mix has sought to achieve this through overcoming market and system failures, there has been limited attention to the *directionality* of change. This is demonstrated on the one hand through the lack of *coordinated policy intervention* in wider application sectors which would be used to generate demand, particularly for innovations that could tackle unsustainable practices in these sectors. On the other hand, the policies which were implemented failed to promote institutionalised *reflexivity* in the innovation system with respect to the sustainability potential of these technologies. Furthermore, in an area like synthetic biology where there promised future benefits are contested, as was described in Section 4.1, the need to establish collective, shared visions for that future becomes even more important. The 2012 roadmap, informed by the 2009 Synthetic Biology Dialogue, did attempt to put forward such a vision. However, as was described in Section 4.3 and by Marris & Calvert (2020), this lacked coherence when it came to considering broader social and environmental value creation (within the framework of RRI) alongside economic value creation. As a result, the policies that have been implemented have had many features that are directed at multiple levels towards actively creating technologies that are commercially viable³⁷, while the creation of technologies that are viable from a social and environmental point of view has not received equivalent attention.

Without explicit attention to *directionality* in the policy mix, the ‘application space’ currently being explored by the field risks failing to deliver on sustainability promises (see Figure 4). It is certainly likely that many synthetic biology applications, if commercially viable, will generate sustainability benefits compared to using fossil fuels³⁸ (top right of Figure 4). However, there are also likely to be trade-offs which without active monitoring and mitigation could undermine promised sustainability benefits (Matthews, Cizauskas, et al., 2019). It also remains the case that despite the introduction of some carbon pricing through emissions trading schemes, most environmental and social value represent externalities from a financial point of view and so there would be little to stop the scale-up of technologies that

³⁷ Examples of this include policy features that encourage researchers to engage with businesses, actively seek to tackle industry-led challenges, and commercialise their research.

³⁸ Indeed, a considerable proportion of the commercial and research activity has been specifically directed at the creation of social and environmental value as well as economic value (Figure 3C; Tables S5 and S6).

inadvertently create new social and environmental problems³⁹ (top left of Figure 4). Furthermore, the necessity of financial value creation (excluding externalities) in present economic systems also leaves an area of unexplored promise (bottom right of Figure 4) where there are environmental and social benefits to be found but a lack of adequate financial return to justify commercial exploitation.⁴⁰

Figure 4: The 'application space' currently being explored by the UK synthetic biology field (Source: author's elaboration drawing on Dyck & Silvestre 2018).

³⁹ Admittedly, reputational damage and environmental regulation can both disincentivise the commercialisation of such applications. However, environmental regulations remain relatively lax and the well-documented and continuing problem of greenwashing can prevent this reputational damage from occurring (Delmas & Burbano, 2012).

⁴⁰ Note that this does not necessarily mean the application is not "commercially viable" in the long-term, but rather that the promised financial returns are not significant enough to justify the potentially risky and long-term investment. This lack of present attractiveness may also be driven by many of the benefits being externalities.

5 Discussion and conclusion

This study has sought to trace the role that sustainability has played in the promotion of synthetic biology in the UK, guided by the analytical framework (Figure 1). Sustainability has formed a significant part of the promise of synthetic biology and has played an important discursive role in establishing joint expectations and thereby legitimising policy intervention in support of this emerging technological paradigm. Yet, this study also identified how this commitment to the creation of broader social and environmental value was not reconciled in policy processes or the policy strategy with the dominant rationale of economic growth through commercialisation. Correspondingly, relatively little attention to sustainability was found in the subsequent policy mix, neither in terms of design and implementation nor in ongoing strategic leadership efforts. This is likely to be resulting in transformational failures in terms of *policy coordination*, *reflexivity*, and *directionality* (Weber & Rohrer, 2012). In this final section, I will draw out the key points from the findings, identify some potential explanations, and suggest some avenues to address them.

I will start by highlighting three key points that may explain why the policy processes and resulting instrument mix developed in this way. Firstly, it is notable how social scientists and the critical insights they bring have been integrated at an early stage into policy discussions, with their most prominent contribution being to introduce and embed RRI within the strategy (Marris & Calvert, 2020). An inability to reach a collective and coherent vision within the policy strategy which reconciled the imperatives of RRI with broader economic goals considerably limited the impact that it could have on the resulting instrument mix and its implementation. This may explain the lack of institutionalised reflexivity which has resulted. It is also important to note that while related, RRI is not synonymous with sustainability and that most researchers brought in to work on RRI would not describe themselves as sustainability researchers. This is despite an assumption that sustainability considerations could be dealt with through RRI activities. The relative absence of other disciplines such as ecologists, environmental scientists, and chemical engineers in both policy discussions and policy implementation suggests that this focus on RRI and the prominent role given primarily to social scientists from STS traditions may have inadvertently crowded out the integration of these other disciplines. This was seen particularly in discussions at the SBLC which tended to focus on commercialisation and RRI, but not sustainability.

A second but related issue centres on the unquestioned link between synthetic biology applications and sustainability, an assumption that was present both explicitly and implicitly in policy discussions. This fed through into the resulting policy strategy and instrument mix which was targeted at promoting the development and commercialisation of synthetic

biology in general with limited attention to whether it delivered sustainable outcomes in the application sectors targeted. Such assumptions about sustainability and a tendency not to problematise it are deep-rooted, and also present in the sustainability transitions literature (see Susur & Karakaya, 2021). However, it is also well-established in the case of bio-based technologies that this assumption of sustainability is flawed (Escobar & Laibach, 2021; French, 2019; Matthews, Cizauskas, et al., 2019; Ögmundarson et al., 2020). More generally, transitioning to a more transformational framing of innovation policy and redressing the deeply embedded unsustainable directionality of present socio-technical change is likely to need more fundamental embedding of these new ambitions within policy strategies, objectives, plans, and instruments (Schot & Kanger, 2018; Schot & Steinmueller, 2018). This study has demonstrated how it is important not to take the sustainability promises of emerging technological paradigms at face value and instead subject them to structured evaluation as is enabled by the analytical framework employed here.

Thirdly, the way in which evolving rationales interacted with a path-dependent instrument mix seems to have played an important role in this case.⁴¹ When the instrument mix was predominantly determined during the c.2012 policy window neither the Paris Agreement nor the SDGs existed while the need for economic growth in the aftermath of the great recession and austerity was particularly urgent.⁴² Meanwhile, the focus on the *Eight Great Technologies* at the time may explain the relative absence of consideration in the policy mix for generating and articulating demand in potential application sectors (Willetts, 2013). As time went on, the focus on sustainability was seen to grow in prominence in policy documents while a return to a more holistic industrial strategy in the broader policy environment provided a potential opening to coordinate synthetic biology policy with intervention in potential application sectors. Given the success the programme seemed to have had in establishing a vibrant and cutting-edge synthetic biology community and a broad range of start-ups pursuing commercialisation, this would have arguably represented an opportune time to integrate more demand-side and explicitly directional policy, as has as have been more extensively used in energy policy (Edler, 2016). However, the 2018 Bioeconomy Strategy does not appear to have so far had the high-level backing to realise this critical evolution of the policy mix.

These issues and challenges aside, the synthetic biology field remains early in development and thereby its impacts remain to a significant extent undetermined. Of course, this also means that the analysis presented here is inherently anticipatory, and therefore the

⁴¹ The importance of these temporal considerations has been previously emphasised in the literature (Edmondson et al., 2018; Flanagan et al., 2011).

⁴² The UK narrowly avoided a “double-dip” recession in 2012.

argument made to some degree conceptually as well as empirically grounded. To what extent synthetic biology on its current trajectory helps or hinders sustainable development will only truly become apparent with time. Nonetheless, technological trajectories are path-dependent and so early decisions matter (Collingridge, 1980). Therefore, despite its limitations, it is an appropriate time to undertake and present this analysis as the field is mature enough to start revealing its trajectory, but before the technologies it underpins have become so embedded in society that modulation and redirection become infeasible.

For the UK synthetic biology community, the policies originally put in place around 2012 are now largely coming to an end while a rebranding exercise is currently underway towards a more application-focussed *engineering biology*.⁴³ In the context of the COVID-19 pandemic, the widely regarded success of the industrial strategy in the context of the Oxford/Astrazeneca vaccine (Balawejder et al., 2021), and a renewed focus on sustainable technologies to assist with the “build back better” agenda (HM Government, 2020), there is the possibility of a new policy window opening which could be used to evolve the policy mix to include more demand-side policies focussed on application sectors.

Based on the findings presented here, I put forward several tentative recommendations for this potential evolution of the policy mix. The first would be to institute more coordinated policy intervention that actively supports the articulation and generation of demand in application sectors such as chemicals, materials, and agriculture. Targeted policies might include public procurement⁴⁴ as well as regulations and incentives⁴⁵. Such policies would likely interact favourably with the new UK-specific Emissions Trading Scheme⁴⁶ in incentivising transitions to lower-emitting bio-based technologies enabled by synthetic biology. Second, existing and new policies need to include stringent minimum sustainability standards rather than simply providing a blanket incentive for bio-based production. To support greater reflexive consideration of sustainability implications, funders and investors could also require elaboration and evidence of sustainability claims in grant applications and evaluations⁴⁷, and be willing to withdraw support if necessary. Third, efforts towards

⁴³ For example, the SBLC was recently renamed the Engineering Biology Leadership Council.

⁴⁴ This could potentially be modelled on the US BioPreferred scheme (USDA, n.d.). In this vein, the UK Government recently announced that a “social value model” will now be integrated into procurement decisions (Cabinet Office, 2020) while the new Industrial Decarbonisation Strategy includes the use of public procurement to promote decarbonisation (HM Government, 2021).

⁴⁵ For example, initiatives like the Renewable Transport Fuel Obligation (RTFO) could be expanded to other sectors such as chemicals and plastics.

⁴⁶ See: <https://www.gov.uk/government/publications/participating-in-the-uk-ets>

⁴⁷ The UKRI environmental sustainability strategy now commits the UK’s principal research funder to implement this (UKRI, 2020).

improved directionality need a collective and shared vision to guide it (Weber & Rohrer, 2012). An opportunity here is provided by the growing interest in the use of citizen assemblies to elaborate on the preferences of citizens (the users) for sustainable technologies.⁴⁸ Synthetic biology research agendas could be (re)directed to try and address the priorities and preferences that emerge from these dialogues. Additionally, foresight activities can help to support improved policy coordination and enable the elaboration of shared visions for sustainable synthetic biology applications, linking up the supply- and demand-sides (Georghiou & Cassingena Harper, 2011).

This article has provided empirical insights from a case study beyond the much-studied domain of energy transitions (Hansmeier et al., 2021; Kern et al., 2019). As transitions are sought in more complex and contested contexts such as those which synthetic biology promises to contribute towards, avoiding taking the sustainability of emerging technologies at face value will become increasingly important (Susur & Karakaya, 2021). Furthermore, policy mixes focussed on indiscriminate support for a given technology are likely to become increasingly ineffective. In line with Flanagan et al. (2011), this study also emphasises the significance of interpretive flexibility in determining the effectiveness of policy instruments in addressing sustainability concerns. There is therefore a need to continue complementing high-level policy mix studies with the in-depth investigation of individual (technological) innovation systems as reported here. In combination, such studies can provide important insights concerning how policy intervention can be used to mobilise STI for sustainable development.

Competing interests

Nicholas E. Matthews was employed part-time as a paid contractor by the UK Government Office for Science during the period that the research for this article was undertaken. During this time, he was not involved in policy relating to synthetic biology. All research for this study was carried out in his capacity as a PhD researcher at the University of Manchester.

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⁴⁸ For example, the UK Climate Assembly recently reported its findings (Climate Assembly UK, 2020).

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Appendix A: Copy of the interview protocol

This interview protocol gives an overview of the questions covered during the interview. The questions aimed to explore the participant's role in the development of the field of synthetic biology in the UK, and their perceptions concerning the role that sustainability has and continues to play in that development.

Visions of sustainability

1. What does synthetic biology mean to you?
2. What does sustainability mean to you?
3. From your perspective, to what extent has sustainability been the rationale for the promotion of synthetic biology in the UK?
 - a. Has sustainability been a stated aim for funders of synthetic biology? Or an underlying implicit aim?
 - b. How about for others engaging with it - researchers, companies, non-profits - to what extent has sustainability been a rationale for them?

Policy implementation

4. In terms of the policies used to promote synthetic biology, I can identify the funding of underlying research, particularly through the SBRCs, building underlying skills through the CDTs and SynbiCITE, the promotion of commercialisation (SynbiCITE and SynBio seed-fund) and the building of networks through the KTN and NIBBs.
 - a. Are there any others I should be aware of?
5. To what extent has a contribution to sustainable development been incentivised in these initiatives?
 - a. Are there specific elements that aim to incentivise more sustainable outcomes? Are initiatives evaluated based on sustainability impacts?
 - b. What attention has there been to evidencing sustainability, such as the use of sustainability assessments?
 - c. Can you tell me of an area where sustainability considerations have specifically influenced decision-making in the field of synthetic biology? This might be by yourself, or others.
6. RRI has been much talked about with respect to synthetic biology, with perhaps unprecedented involvement from social scientists, what do you think has been the impact of this?
 - a. What is the relationship between RRI and sustainability?

- 1164 7. How do the policy initiatives with relation to synthetic biology fit and interact with
1165 broader policy initiatives in the UK and globally?
1166 a. For example, how do policies relating to synthetic biology relate to broader
1167 bioeconomy or industrial biotechnology policy.
1168 b. Are these interactions synergistic? Are they in any way antagonistic?
1169 c. Do you think that synthetic biology policies have encouraged transformation
1170 and/or disruption of existing systems?

1171 **Outputs and evaluation**

- 1172 • What are the metrics for success of synthetic biology? What would “good” look like?
1173 • What would sustainable synthetic biology look like?
1174 ○ What are the possible sustainability benefits of synthetic biology?
1175 ○ What are the possible risks or detrimental sustainability impacts of synthetic
1176 biology?
1177 ○ Are all synthetic biology applications likely to be sustainable?
1178 • Do you think synthetic biology in the UK in its present form is contributing to a
1179 sustainable future? And if so how?

1180 **Wrap-up**

- 1181 • Is there anything you would like to see done differently?
1182 • Are there any people I should talk to, or initiatives/documentation that I should look
1183 at?
1184 • Do you have any questions for me?

1185

1186

Appendix B: Coding manual for supplementary tables

This section of the appendix outlines the coding rules used to generate tables S3-7. Under each heading, the method used to source entries is briefly described as well as the protocol used to determine the value under each field (i.e. column heading).

Table 1

Policies were identified by their inclusion in the “Synthetic Biology for Growth Programme”, through mentions in interviews and other documentary evidence (e.g. news articles or policy reports) or based on the author’s three years of engagement with the synthetic biology community. Only UK government policies initiated between 2012 and 2019 were considered (not EU or Scottish Government policies). A more detailed version of this table is founding Table S4.

- **Policy name:** Policy name as stated in documentation or as commonly known.
- **Date:** Time period over which the policy was active.
- **Approximate Value:** Approximate value of public investment associated with the policy as reported in documentary sources.
- **Type:** Economic instrument, regulation, or information (see Rogge & Reichardt, 2016, Table 2).
- **Purpose:** Technology push, demand-pull, or systemic (see Rogge & Reichardt, 2016, Table 2).

Table S3

Key reports were identified according to their prominence in interviews and other documentary evidence and based on the author’s three years of engagement with the UK synthetic biology community.

- **Report title:** Title as stated.
- **Author:** The organisation or group credited with authoring the report.
- **Date:** Date published as stated in the report.
- **Headline message:** A summary of the report’s main message based on the author’s reading of the report.
- **Recommendations:** A summary of the report’s main recommendations based on the author’s reading of the report.

Table S4

1219 This is a more detailed version of Table 1.

- 1220 • **Policy name:** Policy name as stated in documentation or as commonly known.
- 1221 • **Goal:** “the intended effect of instruments that contribute to achieving overarching
- 1222 policy objectives” (Rogge & Reichardt, 2016, p. 1623)
- 1223 • **Date:** Time period over which the policy was active.
- 1224 • **Approximate Value:** Approximate value of public investment associated with the
- 1225 policy as reported in documentary sources.
- 1226 • **Funder:** Principle source of the funding as reported in documentary sources. EPSRC
- 1227 = Engineering and Physical Science Research Council, BBSRC = Biotechnology and
- 1228 Biological Sciences Research Council, DSTL = Defence Science and Technology
- 1229 Laboratory, BEIS = Department for Business, Energy and Industrial Strategy.
- 1230 BBSRC, EPSRC and Innovate UK are now all part of UK Research & Innovation
- 1231 (UKRI), founded in 2018.
- 1232 • **Type:** Economic instrument, regulation, or information (see Rogge & Reichardt,
- 1233 2016, Table 2).
- 1234 • **Purpose:** Technology push, demand pull, or systemic (see Rogge & Reichardt,
- 1235 2016, Table 2).
- 1236 • **Design features:** Brief description of how the policy was designed and implemented.

1237 **Table S5**

1238 Synthetic biology companies were identified from the following sources:

- 1239 • SynbiCITE’s list of industrial partners (source:
- 1240 <http://www.synbicite.com/collaboration/Partners/type/industrial/>).
- 1241 • Members of the 2017 BioStart synthetic biology accelerator (source:
- 1242 <http://www.synbicite.com/news-events/2017/feb/20/bio-start-selects-first-cohort/>).
- 1243 • Companies that have received funding from the UKI2S seed-fund (source: personal
- 1244 communication).
- 1245 • Spin-outs or collaborators of UK Synthetic Biology Research Centre (source: centre
- 1246 websites).
- 1247 • SynbiCITE’s 2017 Synthetic Biology Start-up Survey (Source: SynBICITE, 2017).
- 1248 Note that the full list for this survey is not publicly available.

1249 In total, 104 candidate companies were identified and screened for inclusion. The following

1250 exclusion criteria were used to filter the candidates:

- 1251 • No detailed information could be found online (e.g. Morph Bioinformatics).

- 1252 • Company no longer exists (was sold or went bust) as of December 2020 (e.g. Green
- 1253 Biologics).
- 1254 • Company not based in the UK (e.g. LanzaTech).
- 1255 • Large company for which specifics on synthetic biology-related operations couldn't
- 1256 be easily identified (e.g. Shell UK).
- 1257 • No evidence of directly using synthetic biology (e.g. London Haskspace, Microsoft).

1258 The remaining 55 companies were then coded according to the following fields:

- 1259 • **Company name:** As stated.
- 1260 • **Source:** From which of the above sources the company was initially identified.
- 1261 • **Application domain:** Classified according to the following options based on the
- 1262 EBRC (2019) classification with "platform & enabling" added to and "Energy" merged
- 1263 with "industrial Biotechnology". The options were as follows:
 - 1264 ○ Platform & Enabling
 - 1265 ○ Health & Medicine
 - 1266 ○ Food & Agriculture
 - 1267 ○ Energy & Industrial Biotechnology
 - 1268 ○ Environmental Biotechnology
- 1269 • **Sustainability or social/environmental value claims:** Whether the company
- 1270 website or other public documentation (e.g. quotes in news articles) made specific
- 1271 claims of improved sustainability or social/environmental value creation from their
- 1272 products or processes. Where the answer is "Yes" a quote is provided. Note that
- 1273 purely working in the domain of Health & Medicine was not in itself considered to
- 1274 constitute a social and environmental value claim.
- 1275 • **Sustainability monitoring and anticipation:** Whether there is evidence on the
- 1276 company website or in other public documentation of specific monitoring or
- 1277 anticipation of claims made. The author looked for activities that sought to reflect on,
- 1278 anticipate and monitor sustainability implications. Examples might include published
- 1279 sustainability assessments or specific collaborations on the topic.

1280 **Table S6**

1281 The websites and other publicly available documentation for each of the six research centres
 1282 funded as part of the synthetic biology for growth programme were reviewed and
 1283 summarised/coded according to the following fields:

- 1284 • **SBRC:** The name of the Synthetic Biology Research Centre.
- 1285 • **Start date:** The date when the grant started.

- 1286 • **Proposal – economic value:** Whether the grant proposal mentions potential
1287 economic value creation.
- 1288 • **Proposal – social or environment value:** Whether the grant proposal mentions
1289 broader social or environmental value creation.
- 1290 • **Stated impact:** Impact of the centre as stated on the website.
- 1291 • **RRI/ELSA activities:** How the centre meets its requirement to undertake RRI/ELSA
1292 activities and research.
- 1293 • **Sustainability monitoring and anticipation:** Whether sustainability monitoring and
1294 anticipation activities are mentioned on the website or other publicly available
1295 information (e.g. publications). The author looked for activities that sought to reflect
1296 on, anticipate and monitor sustainability implications. Examples might include specific
1297 workshops on the topic or published sustainability assessments.

1298 **Table S7**

1299 All publicly available minutes (as of the 7th May 2020) of the synthetic biology leadership
1300 council (SBLC) were reviewed and each meeting summarised/coded according to the
1301 following fields:

- 1302 • **Meeting date:** Date as reported in the minutes.
- 1303 • **Meeting type:** Whether the meeting was of the main SBLC or its Governance Sub-
1304 Group.
- 1305 • **Meeting number:** The meeting number as reported in the minutes. The main council
1306 and its sub-group have separate numbering.
- 1307 • **Economic value creation:** Whether there was discussion of creating economic
1308 value through synthetic biology. For example, discussion of accelerated
1309 commercialisation or IP protection.
- 1310 • **Responsible Research and Innovation:** Whether explicit RRI-related issues were
1311 discussed. For example, discussion of public dialogues/engagement.
- 1312 • **Social or environmental value creation:** Whether there was discussion of creating
1313 broader social or environmental value through synthetic biology. For example,
1314 discussion of actively directing synthetic biology towards societal grand challenges or
1315 the need to evidence sustainability claims. Discussion of engagement with the
1316 Convention on Biological Diversity was generally not in itself considered to be a
1317 discussion of social or environmental value creation as it was mostly focussed
1318 avoiding a moratorium on synthetic biology research and/or applications.
- 1319 • **Key topics:** The main topics discussed at the meeting.