Capturing niche development in secondary disease prevention through a salutogenesis-bioeconomy framework: trends from Kenya

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Abstract: The development of innovation-driven secondary prevention interventions in a niche environment could increase competitiveness in health bioeconomy-related activities. We use trends from Kenya to present a conceptual framework, 'the salutogenesis-bioeconomy framework', illustrating how a knowledge-based bioeconomy contributes to health demand conditions. This conceptualisation sheds light on how preventive medicine interventions in a knowledge-based bioeconomy paradigm can contribute to sustainable niche development and, consequently, competitiveness. Four themes are presented: market prototype innovations, ecological fix innovations, technological fix innovations and techno-ecological fix innovations. This framework elucidates the contribution of preventive medicine interventions to sustainable niche development and health demand conditions in a knowledge-based bioeconomy paradigm.

Keywords: health; bioeconomy; knowledge-systems; economic-transitions; innovation.

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1 Introduction

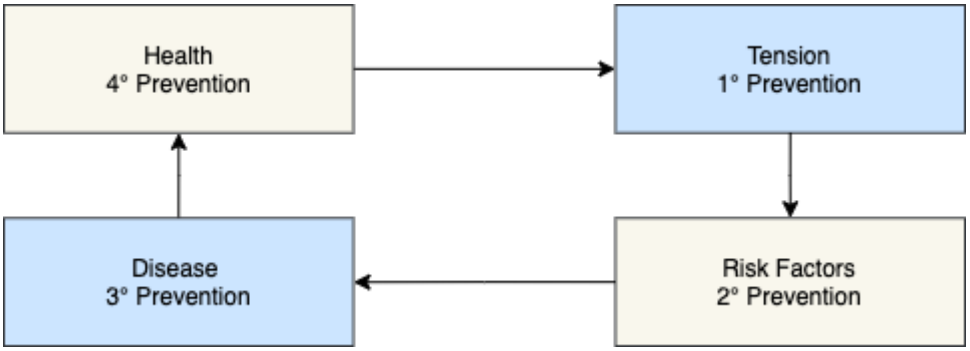
Disease prevention strategies and interventions offer the opportunities to exploit the emerging bioeconomy, leveraging on both ecological and technological fixes. Estimates suggest that about one-third of healthcare's gains are due to prevention, one-third to drug innovation, and the final third to high-tech medical treatments (Dutta et al., 2019). Vaccine development and deployment in communicable disease prevention efforts in Kenya illustrate the necessity of prevention interventions. This class contributes to the highest disease burden in the country (Institute for Health Metrics and Evaluation, 2019), where HIV/AIDS and Malaria are the first-and third-most important causes of years of lost life (YLL), constituting 18.9% and 10.0% of Kenya's total YLL, respectively (Frings et al., 2018). The 2019 Kenya Economic Survey indicates high incidences of communicable diseases in the country, with Malaria consistently being the second most prevalent. The overall incidence of malaria has dropped to 5.37%, although with fluctuating tendencies, but remains the second-highest in prelevance (see Appendix, Table 12) (Kenya National Bureau of Statistics, 2019).

Despite these conditions, according to the Global Innovation Index 2019 (Dutta et al., 2019), Kenya is the second most innovative economy in terms of health and biopharmaceutical innovation in the sub-Saharan African region. Its knowledge-economy related indicators rank it as 61st worldwide in terms of health-related business sophistication and 72nd in terms of knowledge and technology outputs (see Appendix, Table 13). These strengths build on the knowledge-based bioeconomy, understood as "the production, utilization and conservation of biological resources, including related knowledge, science, technology and innovation to provide information, products, processes and services in all economic sectors aiming towards a sustainable economy" (International Advisory Council of the Global Bioeconomy Summit 2018 – IAC-GBC, 2018).

Ecological fixes are strategies for the externalisation and internalisation of environmental conditions in search of profit, by simple commodification of resources. In contrast, technological fixes employ new knowledge and technoscientific developments, or their imaginaries (STEPS Centre, no date) and are enrolled in the real subsumption of nature through increased productivity of biological resources (Birch et al., 2010). They achieve this by leveraging new biology and specialty skills in digital technologies, molecular biology, biochemistry, and an understanding of the microbiome.

The salutogenesis, pathogenesis and leadership of the population, health-transition framework of preventive medicine provides a matrix representation of disease prevention interventions. The process-based part of the framework follows stages designated as 'tension', 'risk factors', 'disease' and 'health', from primary to quaternary prevention (Jadotte et al., 2019) (see Figure 1). Employing bioeconomy niche development theory, we use the saluto-pathogenesis framework to map health bioeconomy interventions and their contributions to health demand conditions to study the introduction, development, and diffusion of radical sustainable technologies in society. Niche development theory is based on the premise that an innovation-driven transformation towards a knowledge-based bioeconomy will be accompanied by the development of dedicated systems of technological innovations generating both income-increasing (quantitative) and structure-changing (qualitative) effects (Pyka and Prettner, 2017).

Figure 1 Saluto-pathogenesis framework (see online version for colours)



We attempt to fill the conceptual gap regarding how, through the concepts of ecological and technological fixes, the knowledge-based bioeconomy narrative can transform how firms meet demand conditions. Secondly, we attempt to address the limited considerations of health interventions as a part of the bioeconomy paradigm, primarily

where there is reduced focus on biological resource management. The health bioeconomy, through the emergent bio-revolution, is bringing with it a new array of capabilities that will fundamentally transform how companies compete. New specialty skills in digital technologies, molecular biology, biochemistry, and an understanding of the microbiome are in growing demand as they are increasingly employed in the real subsumption of nature. Therefore, we use the trends from Kenya to present a conceptual framework, "the salutogenesis-bioeconomy framework", that shows how a knowledge-based bioeconomy contributes to health bioeconomy demand conditions.

2 Literature review

Mittra and Zoukas (2019) classify the bioeconomy into broad fields whose boundaries may sometimes overlap, i.e., white (used in industrial biotechnology and sustainable energy), red (employed in health and pharmaceuticals), green (agriculture and food), and blue biotechnology. The health domain is part of the bioeconomy; however, the current discourse often side-lines it due to its dependence on a combination of 'white', 'green', 'blue' and 'red' biotechnology rather than primary dependence on biomass associated green biotechnology.

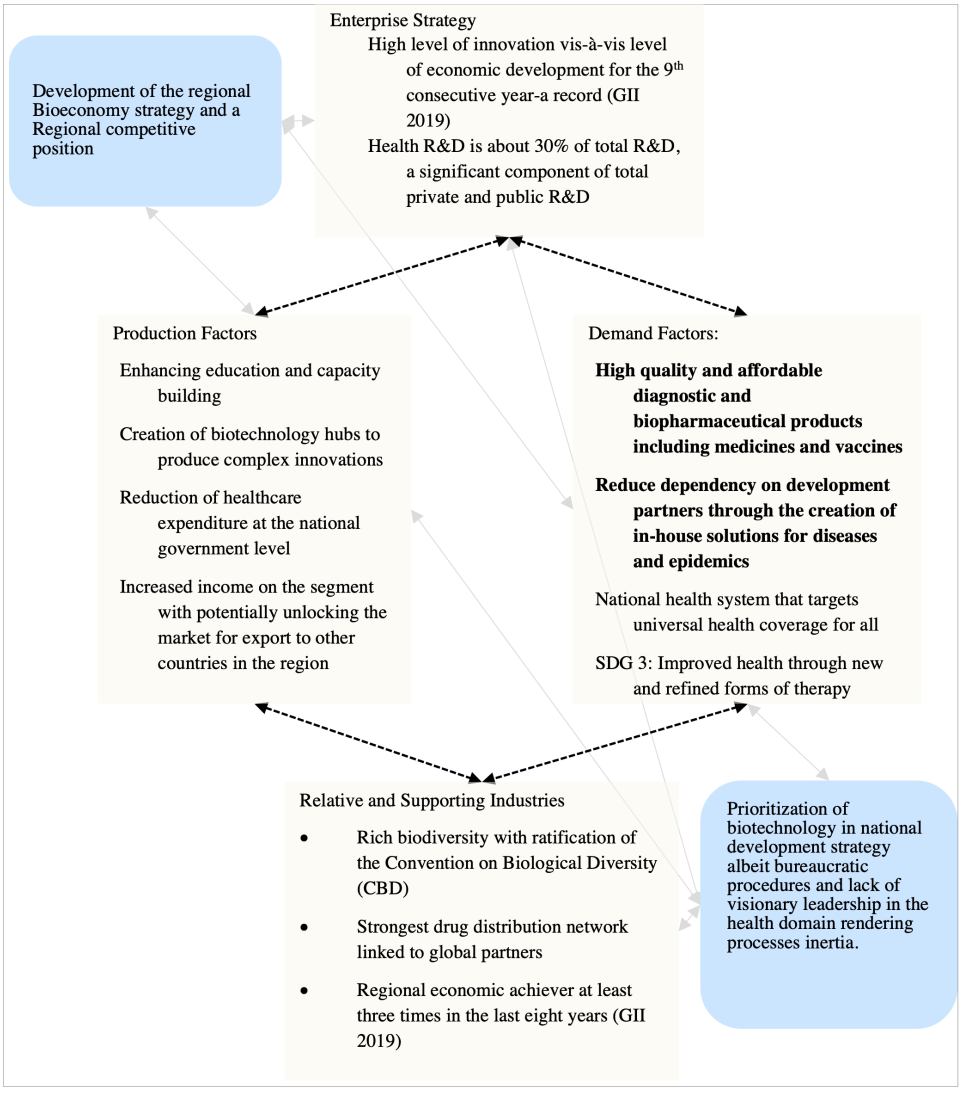
While Birch et al. (2010) present the concept of ecological and technological fixes comprising a bioeconomy, they do not explicitly provide for how these narratives can transform how firms compete to meet present market demand conditions. Ecological fixes allow for the externalisation and internalisation of environmental conditions and are often enrolled in nature's formal subsumption. Technological fixes use new knowledge and technoscientific developments, or their imaginaries, which are then enrolled in nature's real subsumption. A convergence of these two solutions creates knowledge-based bioeconomies (Birch et al., 2010).

Therefore, the health domain leverages the knowledge derived from the understanding of biological systems including human, animal and plant health. It can be considered as a knowledge-based bioeconomy, a strategy for sustainable capital with an increasing emphasis on both ecological and technological fixes (Birch et al., 2010; Wield et al., 2013; Devaney and Henchion, 2018; Vivien et al., 2019).

Demand factors for a health bioeconomy in preventive medicine in Kenya include the need for high quality and affordable diagnostic and biopharmaceutical products, particularly medicines and vaccines and a reduced dependency on development partners through creating in-house solutions for diseases and epidemics. Other macro-level conditions include establishing a national health initiative that targets universal health coverage and addressing the United Nations' third Sustainable Development Goal. We focus on the first two demand conditions to explore how secondary disease prevention in knowledge-based bioeconomy perspectives can contribute to sustainable niche development around communicable disease prevention innovations. In some feedback loops, these factors are considered to influence the production factors, including the creation of biotechnology hubs to produce complex innovations. Increased income in the segment could unlock the export market and reduce healthcare expenditure at the national government level (see Figure 2).

Secondary prevention comprises disease prevention and risk factor management, including diagnostic screening and disease prophylactic strategies. In Kenya, as of 2016, approximately 940,000 adults and 60,000 children (i.e. 64% and 65% respectively) had access to antiretroviral treatment (ART) (Mugo et al., 2017). Since 2004, the country's National Malaria treatment guidelines have stipulated artemisinin-based combination therapy as the reference therapy, with confirmatory diagnosis recommended in all cases since 2014 (Amin et al., 2007; Musuva et al., 2017).

Figure 2 Competitiveness of Kenya's health bioeconomy domain using the porter diamond model (see online version for colours)



We focus on the two demand factors for a health bioeconomy, i.e., the need for high quality and affordable biopharmaceutical products, including medicines and vaccines and reduced dependency on development partners by creating in-house solutions for diseases

and epidemics. It is anticipated that an investigation of these demand factors will shed light on how secondary disease prevention through knowledge-based bioeconomy paradigm can contribute to sustainable niche development.

Sustainable niche development positions the bioeconomy as an enabler of development of different sectors. While industry-oriented organisations have made attempts to classify the bioeconomy using sector perspectives, some innovation scholars and policymakers argue that the bioeconomy cannot be viewed as such. These scholars, especially in the knowledge economy field, recognise the bioeconomy as a cross-disciplinary environment and see partnerships as fundamental to enhance bioeconomy development. A systems perspective is employed, interlinking evolving knowledge domains and dynamic system actors to capture future opportunities for value creation. For this reason, the network of firms and actors, or niches, is the locus of innovation, making a theme-based approach more expedient for analysis of bioeconomy systems (Golembiewski et al., 2015).

Niches are understood as dedicated systems of technological innovations generating both income-increasing (quantitative) and structure-changing (qualitative) effects (Pyka and Prettner, 2017). This concept is lodged within the theory of strategic niche development, which advocates for creating socio-technical experiments in which various innovation actors are encouraged to collaborate and exchange information, knowledge, and experience, embarking on interactive learning processes that facilitate the incubation of new technologies. Products developed in specific niches have distinct development properties including the following, as described by Caniëls and Romijn (2008):

1 developed in a sheltered place for incubation

2 have the possibility for continuous evaluation and incremental improvement through broad stakeholder interaction processes

3 exhibited temporal increasing returns or learning economies'

4 are still open to development in different directions

5 are already attractive to use for certain applications in which the disadvantages of the new technology are of lesser importance and the advantages are highly valued.

Examples of bioeconomy-related niches would include wood-based industries, oil-based industries, even cosmetic-based industries, or, as interpreted here, disease prevention interventions as the nth niche (see Figure 3).

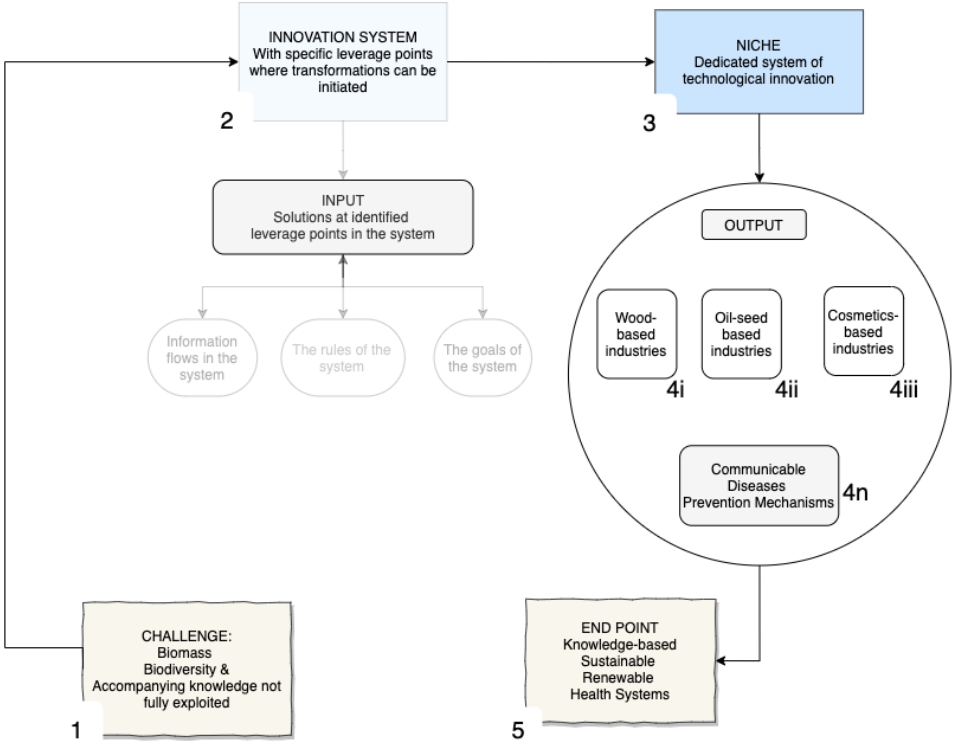
Therefore, we present the health bioeconomy as a solution to a perceived challenge by industry to respond to demand conditions, discussed as the need for high quality and affordable biopharmaceutical products including medicines and vaccines, and reduced dependency on development partners by creating in-house solutions for diseases and epidemics. We explore secondary preventive medicine interventions combining ecological and technological fixes and investigate their perceived contribution of these to meeting the demand conditions for a health bioeconomy through a set of semi-structured interviews coupled with extensive literature reviews. It is expected that these interventions will champion the creation of niches to produce innovations even within such complex innovation systems.

3 Methods

Understanding secondary disease prevention interventions in communicable diseases and addressing demands in the health bioeconomy is the primary relationship under investigation (see parts 3, 4 and 5 of Figure 3).

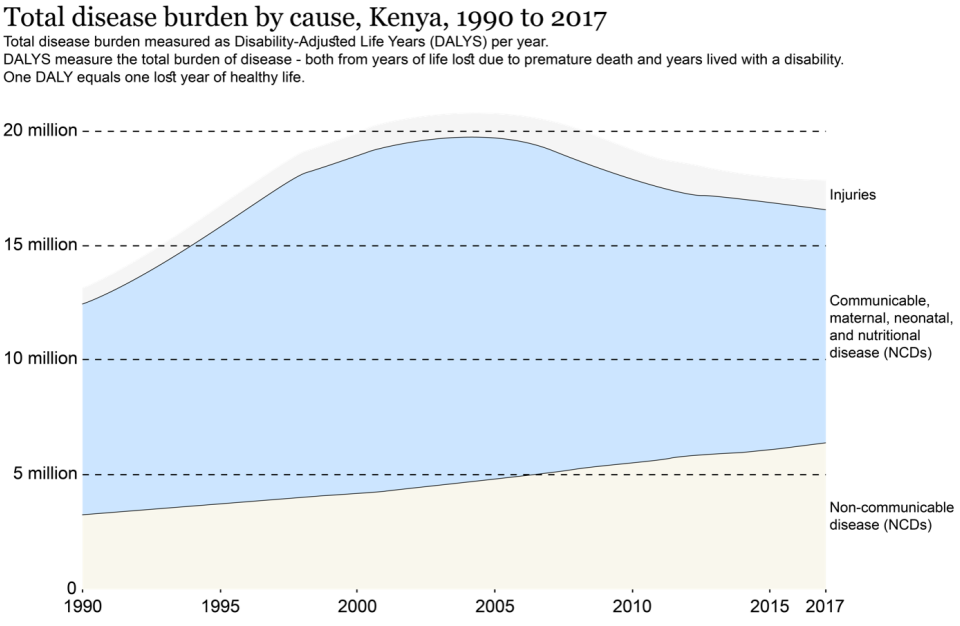
We use trends from Kenya to present a conceptual framework, termed here 'the salutogenesis-bioeconomy framework'. The salutogenesis framework presented previously (see Figure 1) is used to map preventive medicine approaches in which adjustments are made to accommodate bioeconomy principles (see Figure 5). This section presents the methods employed in developing the conceptual framework and discusses why and how case studies are used as a qualitative method.

Figure 3 Preventive medicines as a pathway for bioeconomy transformation (see online version for colours)



Health research and innovation activities in the country reveal the significant presence of preventive medicine interventions. Like many developing economies, Kenya is facing a double burden of disease: generally, earlier achievements in public health and medicine have led to an epidemiologic transition, with population morbidity moving from infectious to mainly chronic conditions. Despite these, substantial population health improvements in terms of communicable diseases have not materialised (Figure 4).

Figure 4 Total disease burden by cause, Kenya, 1990 to 2017 (see online version for colours)



Source: IHME, Global Burden of Disease; https://ourworldindata.org/grapher/total-disease-burden-by-cause?country=KEN

The contributors to the highest disease burden in Kenya, i.e., communicable diseases, mainly AIDS, Malaria, Tuberculosis and respiratory diseases, provide the specific context for the focus on secondary disease prevention (Institute for Health Metrics and Evaluation, 2019). AIDS and Malaria are the first and third most important causes of YLL, constituting 18.9% and 10.0% of Kenya's total YLL, respectively (Frings et al., 2018).

We employed a qualitative research approach to gather the primary and the secondary data to develop the proposed framework. Semi-structured interviews were conducted using purposive sampling. Research directors, pharmaceutical directors and innovators were interviewed through a snowballing process on health bioeconomy in Kenya to gain additional detailed information on the case studies to understand health bioeconomy transformation trends. Secondary data were obtained from the literature, primarily on the bioeconomy, secondary disease prevention in communicable diseases, innovation systems, and strategic niche management is studied to provide secondary data.

Using this data to investigate the development of niches specific for secondary disease prevention in AIDS and Malaria, we propose the salutogenesis-bioeconomy framework with a view to identifying bioeconomy principles and applications in secondary disease prevention, as discussed in the next section. This framework was developed using a step-wide approach as follows: firstly, we identified the interventions proposed in the original framework and their relationships to dominant preventive medicine trends in Kenya. This interpretation was triangulated with the definitions provided through the Global Innovation Index Report of 2019 that focuses on Health (Dutta et al., 2019). We concentrated on disease and pathogenic factors presented in

secondary prevention, otherwise known as 'risk factor' management, as seen on the second quadrant of the salutogenesis framework (see Figure 1).

Next, the fundamental knowledge-based bioeconomy principles – green biotechnology, red biotechnology, white biotechnology, blue biotechnology and the neo-liberalisation of nature – were discussed in light of the advantages these innovations confer. These advantages were assessed along the two critical axes: innovation development in a bioeconomy niche environment (technological fix) and its properties that would provide an ecological fix to prevalent bioeconomy environmental conditions.

Finally, mapping was carried out based on niche development in the bioeconomy to confirm, using the pre-identified niche criterion (Caniëls and Romijn, 2008), the hypothesis that secondary preventive medicine interventions in HIV and Malaria constitute a niche for the bioeconomy. This last step is based on the observation that given the interdisciplinarity and the reduced coordination experienced in niches, they provide an environment for the generation of technologies and innovations, i.e., their structural frameworks can be varied in nature provided that novel technologies are produced from these interactions.

4 Results

4.1 Salutogenesis-Bioeconomy framework

The salutogenesis framework (c.f., Figure 1) aligns with the World Health Organisation (WHO) health definition of health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (World Health Organisation, 1948), by mapping interventions along the disease-death continuum. However, this original framework does not define how interventions align with bioeconomy principles, which would illustrate how the select interventions accommodate the sustainable and innovative use of biomass, accompanied by exploitation of biological knowledge. We propose the salutogenesis-bioeconomy framework (see Figure 5) mapping interventions along two axes: innovation development in a bioeconomy niche environment (technological fix) and its properties that would provide an ecological fix to prevalent bioeconomy environmental conditions. A desired intervention output would be a knowledge-based, sustainable, renewable, health-system-ready innovation.

4.2 Trends in secondary preventive medicine mapped along the salutogenesis-bioeconomy framework

Secondary prevention entails disease prevention and risk factor management, with the central processes including diagnostic screening and disease prophylactic strategies (Jadotte et al., 2019). Focusing on AIDS and Malaria disease-related interventions, we discuss some trends in bioeconomy related technologies that result from secondary prevention technologies along the illustrated salutogenesis-bioeconomy framework. In terms of their perception of conversance with bioeconomy principles, participants with 'techno-ecological fix' innovations emerge being the most exposed to the bioeconomy discourse (see Figure 6), linking 'use' of 'biological resources' or 'biomedical solutions' to 'economic development'.

Figure 5 Salutogenesis-bioeconomy framework (see online version for colours)

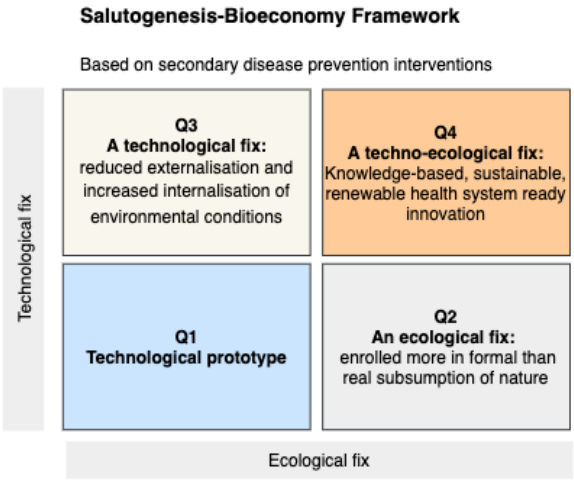
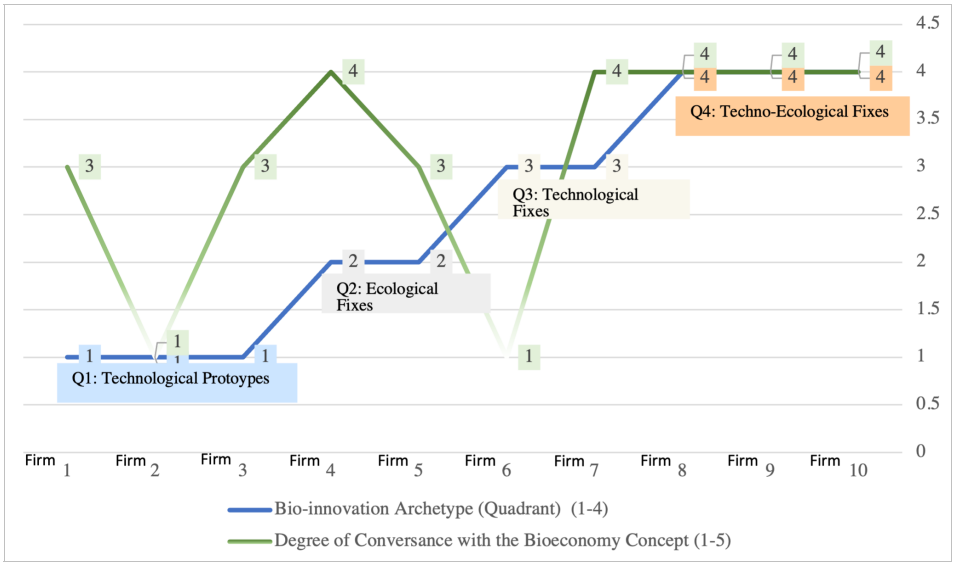


Figure 6 Degree of conversance with the bioeconomy concept (see online version for colours)



We describe below the assumptions underpinning the four quadrants of our salutogenesis-bioeconomy framework (Q1 – 'technological prototypes', Q2 – 'ecological fixes', Q3 – 'technological fixes', and Q4 – 'techno-ecological fixes') and the characteristics of associated case examples:

4.2.1 Technological prototypes

Like market prototypes, technological prototypes focus on testing the desirability of an innovation by making it tangibly affordable and sustainably disposable. They allow for quick idea validation based on direct testing for feasibility, marketability, and feedback

receipt in realistic terms. Products or services in the technological prototype can either be successful from the outset or fail; however, the prototype is not usually at the final product development stage but can be improved after testing. After this stage, such innovations can be housed in incubation or technological platforms. Improvements tend to focus on quality, technological performance optimisation, nature subsumption optimisation and development effectiveness or a mixture of these. Case examples in this trend include:

Firm 1: Ilara health (affordable diagnostics)

Ilara Health makes common diagnostics accessible and affordable by partnering with companies using robotics and artificial intelligence to lower their cost. A platform within an innovation platform, it is housed at Villgro Africa, an incubation platform in Nairobi that supports innovators in diagnostics through funding, mentorship, and networking. The innovation supports the development of biomedical care innovations employing white biotechnology to develop the diagnostic tools in Ultrasound, HbA1c, haemoglobin and eye test, and red biotechnology for the biomedical applications in diagnostic screening interventions. Ilara Health's niche innovation dynamics are as shown in Table 1.

Table 1 Ilara health niche innovation dynamics

	Firm 1: Ilara Health	
Bioeconomy principles involved	White technology in the development of screening devices and red biotechnology in designing the medical applications necessary for the diagnostic devices to function.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* The platform is incubated at Villgro Africa and enjoys the advantages of operating within a network of other firms to share best practices and improve the products.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* The products are subject to regulatory requirements within the health sector, requiring precision and accuracy testing on a regular basis. Continuous studies are conducted to ensure that they address emergent requirements.
	Exhibited temporal increasing returns or learning economies.	*Yes:* The products have undergone numerous improvements since their conceptualisation, thanks to the feedback received during tests by users.
Niche development and competitiveness implications	Still open to development in different directions.	*Yes:* Apart from Malaria and HIV, the products are being tested for use in other diseases such as Covid-19 and other communicable diseases.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*No:* Thanks to the advances and with regulatory agency requirements, the advantages of using the devices are being recognised. However, the products are yet to be accepted by users in health facilities as some regulatory conditions are still unmet.

Firm 2: Matibabu device (malaria diagnostics)

Matibabu Device provides health authorities with information about Malaria prevalence using magnesium and light-based geothermal referencing. Developed by Mr. Brian Gitta, a 24-year-old innovator from Uganda, and his team, the device received international recognition after winning the Royal Academy of Engineering's Africa Prize in June 2018. They report that the use of biological resources has reduced environmental pollution, thus making their innovation competitive. This innovation was incubated at Villgro Africa. The platform, in addition, collects data whose visual perception helps run prediction algorithms to deduce geographically customised Malaria trends, participating in surveillance. Matibabu device supports the development of biomedical care innovations employing white biotechnology to develop screening and diagnostic tools and red biotechnology for biomedical applications. Matibabu device' niche innovation dynamics are as shown in Table 2.

Table 2 Matibabu health niche innovation dynamics

	Firm 2: Matibabu health	
Bioeconomy principles involved	White biotechnology in the development of diagnostic tools and red biotechnology in designing the medical applications necessary for the device to function.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* The product has been incubated successfully in various platforms, including Villgro Africa. Through the international recognition it has received, global researchers have provided feedback on how to improve its diagnostic precision and accuracy.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* There is a research unit dedicated to exploring modern technologies and increasing knowledge to improve the product.
	Exhibited temporal increasing returns or learning economies.	*Yes:* Since its inception, the product has improved significantly, thanks to the exposure received in the incubation platforms.
Niche development and competitiveness implications	Still open to development in different directions.	*Yes:* There are numerous applications of the technologies used in this product that could be applied to other diseases, particularly the neglected tropical diseases.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*No:* While approval for the product is being sought through the regulatory agencies, it is yet to be accepted for use in primary health facilities.

Firm 3: Mama Ope (pneumonia diagnostics)

A vest capable detecting pneumonia in children using auditory and respiratory metrics, Mama Ope leverages time efficiencies and ease of use to promote faster and more

accurate pneumonia diagnosis. The biomedical smart jacket distinguishes the symptoms of pneumonia – temperature, breathing rate and the lung sounds – and eliminates most human error; this will help community health workers, clinicians, and nurses measure pneumonia symptoms accurately and in good time. This innovation is also incubated at Villgro Africa. It employs biomedical care translation into medical care applications. The firm report that biological resources do not necessarily provide a significant competitive advantage to the firm. This observation could be attributed to their real subsumption of nature. They are employing knowledge on biological systems in white biotechnology and would apparently not be considered to be using bio-resources per-se. Mama Ope's niche innovation dynamics are as shown in Table 3.

Table 3 Mama Ope's niche innovation dynamics

	Firm 2: Mama Ope	
Bioeconomy principles involved	White biotechnology in the development of diagnostic tools and red biotechnology for medical care applications.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* The device has been developed in an incubated lab setting, including at Villgro Africa, and tested before usage.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* By engaging the future users/customers such as medical practitioners, they have been able to get early feedback to help improve.
	Exhibited temporal increasing returns or learning economies.	*Yes:* Since the conceptual days until now, numerous improvements have been made to the product.
	Still open to development in different directions.	*Yes:* The more interactions are held with stakeholders; the more insights are obtained to understand and learn about what the device is capable of.
Niche development and competitiveness implications	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*Yes:* Users are already aware of the needs the device can serve.

4.2.2 Ecological fixes

Ecological fixes are strategies for the externalisation and internalisation of environmental conditions in search of profit. Our framework presupposes that ecological-fix innovations are not often created in a niche environment and may not have the transferability and interoperability that other technological-fix innovations may have. Some of the interventions in ecological fixes range from ecosystem-based approaches, such as rehabilitating degraded land for biomass production and other ecosystem services, to protecting biodiversity, reversing critical trends of natural resource overexploitation and environmental degradation. In health-related interventions, this may also include the formal subsumption of nature depicted as the transformation nature into resources through commodification following extraction, by analogy to labour exploitation (Birch et al., 2010). Case examples in this trend include:

Firm 4: Sahrec enterprises (chemo-pro-phylactic relief using medicinal plants)

Songo Herbal African Research Centre (SAHREC) Enterprises uses biological natural resources to generate income and useful products such as medicines for health and foods for natural remedies. These products, including *Songo Prot* are reported to boost body immunity to prevent severe inflammatory flares, participating in harm reduction. While *Songo Prot* has undergone scientific testing and has been found to be safe through clinical trials, funding was not available to have it undergo complete efficacy testing. It has been registered as a utility model through the Kenya Industrial Property Institute (KIPI) and licensed by the Ministry of Health. In Kenya, the use of medicinal plants' use as a fundamental component of the African traditional healthcare system is perhaps the oldest and the most assorted of all therapeutic systems. With estimates indicating that about where 70-80% of the population relies on traditional medicine for disease prevention, the role of nutraceuticals through food and nutrition security cannot be underestimated (Mahomoodally, 2013). The use of these plants has apparently continued to provide chemo-pro-phylactic relief to people predisposed to Malaria and to HIV co-infections. In 1984, a Centre for Traditional Medicines and Drugs Research was established as part of the Kenya Medical Research Institute (KEMRI), following the WHO's Alma Ata Declaration, which promoted the role of healers in delivering primary care (The International Conference on Primary Health Care, 1978).

Table 4 Niche innovation dynamics of Sahrec enterprises – anti-inflammatory relief provided by nutraceutical and aromatic plants

	Firm 4: Sahrec enterprises	
Bioeconomy principles involved	Green Biotechnology in the externalisation of herbal, environmental and biological properties. The reregulation of traditional medicine practice through the Ministry of Culture.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*No:* Externalisation of environmental conditions is exercised. However, traditional medicine has been criticised for its failure to provide proper documentation of the herbs' properties. The enterprises are receiving policy support to develop a community of practice through the Ministry of Culture, both at the national and county level.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* Reportedly, engagement with other stakeholders will enable to the improvement of services.
	Exhibited temporal increasing returns or learning economies.	*No:* Tacit knowledge is passed on from generation to generation. With growing urbanisation, there is frequently a missing link in the knowledge transmission chain. In addition, the scaling of these innovations has proven a challenge due to the lack of formal R&D and overemphasis of western pharmaceuticals in the health system. However, benchmarking exercises would reportedly help improve the services.

Table 4 Niche innovation dynamics of Sahrec enterprises – anti-inflammatory relief provided by nutraceutical and aromatic plants (continued)

	Firm 4: Sahrec enterprises	
	Still open to development in different directions.	*Yes:* There is room for improvement as work is continually engaged to improve their research and services for clients.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*No:* Traditional medicine herbal healers in Kenya are currently licensed by the Ministry of Culture, which requires a testament of good character from the chief in the area where they work and a letter from a medical research institute stating that the herbs they use are traditionally recognised as having a medicinal effect. Their products have been used, and no harm or side effects have been reported for more than 20 years.

Reportedly, the use of biological products has carved a niche for Sahrec Enterprises in immunity boosting. The niche innovation dynamics of Sahrec Enterprises is as shown in Table 4.

Firm 5: Zion Herbal (anti-inflammatory relief provided from nutraceutical and aromatic plants')

Based in Bungoma, Western Kenya, Zion Herbal is one of the many traditional medicine firms providing chemo-pro-phylactic relief to patients in the country. Their strategies are in both externalisation (through direct reliance on natural products) and internalisation (through the anti-inflammatory actions of the plant) of environmental conditions in search of profit. The firm reports that these strategies contribute to the bioeconomy by using biodiversity extracts and knowledge viably, contributing to harm reduction strategies. Anti-inflammatory properties are found in plants such as the Drumstick Tree (*Moringa oleifera*), Blackjack (*Bidens pilosa or Makowee* in Bukusu dialect), or Valh (*Carissa edulis* or *Sirwa* in the Bukusu dialect). *Makowee* has reported i mmunity-boosting effects, and Sirwa has reported effects on flu like symptoms, vomiting, kidney problem and epilepsy and is considered to be immunity-boosting for AIDS patients. Conservation of these plants is important through infrastructure such as the Kakamega Forest National Reserve. Zion Herbal's niche innovation dynamics are as shown in Table 5.

Table 5 Zion Herbal-Chemo-pro-phylactic relief from medicinal and aromatic plants niche innovation dynamics

	Firm 5: Zion Herbal	
Bioeconomy principles involved	Green biotechnology in the internalisation of the plants' environmental and biological properties with medicinal chemo-phylactic properties and formal research.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* Innovation was incubated once at the Kenya Industrial Research and Development Institute (KIRDI) in 2004 for six (6) months. However, this privilege is not afforded to a lot of other herbalists who often do not have the financial means or confidence to seek incubation.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* They have collaborated with KEMRI, KIRDI, University of Nairobi, Kenyatta University, North and South Carolina, among others, to enhance the products and provide scientific input into the work. However, joint intellectual property modalities are often not spelt out clearly, which makes herbalists avoid such collaborations.
	Exhibited temporal increasing returns or learning economies.	*Yes:* There has been continual improvement due to the exposure to other partners and practitioners. They continue to seek out plants that are more potent and apply scientific principles to make improvements.
	Still open to development in different directions.	*Yes:* There is potential for improvement mainly in terms of large-scale clinical trials particularly in Covid-19 – some plants with anti-inflammatory properties can be used across various diseases. There is an opportunity to test this kind of efficacy using scientific principles and through clinical trials.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*Yes:* Many patients consider these products to be among the best among immune boosters while others use them in addition to conventional medicines provided at the primary healthcare facilities.

4.2.3 Technological fixes

Some innovations may be developed in a strategic niche environment and use the latest technologies available. However, they may lack the ability to solve ecological challenges through externalisation or internalisation of environmental conditions. Technological fixes use new knowledge and technoscientific developments or their imaginaries (STEPS Centre, no date). These are enrolled in the real subsumption of nature through its

intensification by increasing the productivity of biological resources (Birch et al., 2010). This framework presupposes that technological-fix innovations are created in a niche environment and hence have the transferability and interoperability that other ecological-fix innovations may not have. For instance, some screening and diagnostic tools have been developed in Kenya over the years, facilitating early and accurate diagnosis. Through analogies, diagnostic tools for other pathogen-induced infections are inspired by those already developed for other infections. Case examples in this trend include:

Firm 6: NASCOP HIV self testing (HIVST) kit

The National AIDS & STI Control Program (NASCOP) has made available HIV self-testing kits available in public and private facilities to encourage testing and recourse to early treatment. A campaign website includes interactive videos demonstrating the use of the kits and explaining what to do in the event of positive or negative results. More recently, especially with the advent of the Covid-19 pandemic, the program has specifically promoted self-testing and the provision of the self-diagnosis tools through over-the-counter dispensation, even through online pharmacies with at-home-deliveries. The self-testing kit ensures a clear transition to biomedical care initiation for better health and disease management in the event of a positive result. The participants report little understanding of what bioeconomy means as much as there they have ongoing bioeconomy-related activities in action. Sensitisation of actors would lead to an increase in their contributions to policy dialogue. However, as a concepts, preventive medicine measures seem to be well understood as "know-how and practices used to prevent an individual from developing a disease".

This case example illustrates how biomedical care can be translated into better care, employing process and marketing innovation to address public health concerns. The firm employs white biotechnology to develop the self-diagnostic tools and red biotechnology in the medical applications for positive cases by providing pre-exposure prophylaxes post-exposure treatment. The use of biological resources in the firm provides a medical care edge by improving responses vis-à-vis patient self-management interventions. Their niche innovation dynamics are as shown in Table 6.

Firm 7: HIV prevention program – surveillance and research

Strategic information, research and implementation science in the NASCOP HIV Prevention Programme is essential for the early identification of both infection and new virus strains to ensure that patients can benefit from newly available antiretroviral therapies. The aim of the surveillance mechanisms in place is to translate biomedical research into better care. The conduct biomedical research using implementation science on routine HIV Programmes, generating new knowledge that informs the respective programs' implementation in developing new products or improving existing treatment regimens.

Table 6 NASCOP HIV self testing (HIVST) kit niche innovation dynamics

	Firm 6: NASCOP HIV self testing (HIVST) Kit	
Bioeconomy principles involved	White biotechnology in the development of the diagnostic tools and Red biotechnology for medical applications for positive cases.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* Blinded blood samples are used for proficiency testing in HIV testing. In addition, the marketing innovations employed in increasing heightened awareness of self-testing are regulated by national and sector-specific policies and procedures.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* There is an increasing need for demand creation to scale up HIVST PrEP and other strategies. Furthermore, in consultation with firms carrying out product development, such as Roche and Ora Sure, and in collaboration with colleagues working in reproductive health, the firm is currently exploring the possibility of developing PrEP injectables, replacing daily tablets with monthly injections. If this strategy is adopted, dispensing sites and appropriate storage capacity will be required.
	Exhibited temporal increasing returns or learning economies.	*Yes:* There has been much improvement in demand creation, especially during the Covid-19 period of self-isolation and quarantine. Marketing campaigns have been carried out to normalise self-testing and studies with different populations have been conducted. There are plans to set up vending machines for the kits, even further together with the aforementioned PrEP injectables.
	Still open to development in different directions.	*Yes:* There is a need to work on the products availability, potentially providing them free of charge. There are still avenues for scaling up the different products, including a switch to an off-the -shelf policy. This new method is likely to be deployed together with other reproductive health commodities too. However, there are significant policy limitations due to health sector regulations.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*No:* There are still a lot of bureaucratic bottlenecks in the implementation of the interventions. While studies demonstrating the efficacy of these interventions have already been conducted, reduced complementarity with partner agencies means that the rollouts are not as effective, even though there is a clear market opportunity especially among the youther population.

As one of the pillar axes of the program, they are involved in screening actions, in which they employ red biotechnology using knowledge of chemoprophylaxis in HIV antiretroviral treatments interventions. For instance, during the clinal trials on *Doulotegravir*, the neural effects of the drug on babies were not established, information which was subsequently available thanks to the surveillance research (Nkala, 2018; Phillips et al., 2019; Chouchana et al., 2020). Another example is the *Efavirance* antiretroviral which was found to have hallucinogenic effects during the surveillance

research conducted at the population level (Gatch et al., 2013). The HIV Prevention Program's niche innovation dynamics are as shown in Table 7.

Table 7 HIV and STI prevention programme – surveillance and research niche innovation dynamics

	CE 7: HIV and STI prevention programme – surveillance and research	
Bioeconomy principles involved	Red biotechnology where knowledge of chemoprophylaxis is applied in HIV antiretroviral treatment interventions.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* M&E frameworks that have been developed, enabling the firm to generate data, which they seek to use to inform policy in subsequent policy reviews.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* Continuous improvement can be achieved particularly in training and reinforcing staff to implement science research approaches. Most of the time, the program runs with too few staff but increasing partner demands. These same individuals are also custodians of national/ministry resources, a role that may not be visible to partners. If strengthened, this role would ensure that national resources and priorities are safeguarded.
	Exhibited temporal increasing returns or learning economies.	*Yes:* There have been numerous improvements proposed through the knowledge products generated by the firm. For instance, the information on *Doluotegravir* and *Efavirance* antiretrovirals could only be learnt through the implementation research.
	Still open to development in different directions.	*Yes:* The firm possesses a mine of data that could allow for the development of numerous other products. For instance, they could provide information on the prevalence of vaccine-preventable diseases and the migration of different disease strains. This data can also be used to provide validation evidence for given interventions such as the President's Emergency Plan For Relief AIDS (PEPFAR).
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*Yes:* Located at the heart of the national health system, they do not face many bottlenecks in the implementation or the attractiveness of their interventions.

4.2.4 Techno-ecological fixes, knowledge-based bioeconomy innovations

Our framework presupposes that techno-ecological fixes and their innovations are created in a niche environment and present transferability and interoperability between different applications. These are enrolled in the real subsumption of nature and employ strategies

of externalisation and internalisation of environmental conditions searching for profit. Case examples in this trend include:

Firm 8: CREATES (pre-clinical and clinical studies)

The Centre for Research in Therapeutic Sciences (CREATES) is a consortium and innovation platform that provides health solutions through tailored health innovations, including pre-clinical and clinical studies for targeted therapies in HIV and Malaria. It acts as a catalyst for product development and provides a product development platform within what we can now call the bioeconomy. However, the firm is looking more at the biotech platform for Kenya, including harnessing nanotechnology for product development. A part of their research agenda is to work with colleagues from environment-studies based disciplines to assess the impact of climate on health and to understand disease trends and drivers. They are involved in biomedical care in the drug development and testing phases, applying red biotechnology in the medical and chemical application processes. Being a platform in and of itself, the centre provides a niche environment for innovation development for disease prophylaxis and diagnostic screening. Their specific niche innovation dynamics are as shown in Table 8.

Table 8 CREATES (pre-clinical and clinical studies) niche innovation dynamics

	Firm 8: CREATES (pre-clinical and clinical studies)	
Bioeconomy principles involved	Red biotechnology for the medical/chemical applications.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* Bioeconomy product development requires a set of disciplines that possibly will not be hosted in any one institution at any given time. Some of them are not even housed in one country. This requires removing all the boundaries that exists. A product may be developed in Kenya but may subsequently go through several labs and be handled by different people, teams, and different institutions in order to expedite the process, rather than having to develop the requisite infrastructure in one place, which might take much longer.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* By applying the most recent or available technologies to improve health of the population at large and help to reduce their susceptibility and proximity to disease, making them much more productive and improving their quality of life.
	Exhibited temporal increasing returns or learning economies.	*Yes:* Kenya did not have a nanotechnology platform for a given project at the Centre. The nanotechnology platform needed was available in South Africa, so the solution was to come up with ideas and select a team of Kenyans to South Africa with an exact product that we wanted to develop. This team would spend time in the lab, develop the product and bring it back to be tested by the centre.

Table 8 CREATES (pre-clinical and clinical studies) niche innovation dynamics (continued)

	Firm 8: CREATES (pre-clinical and clinical studies)	
Niche development and competitiveness implications	Still open to development in different directions.	*Yes:* Collaborating more with environment-based practitioners, looking at the impact of climate on health and how this influences disease trends.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*No:* The bioeconomy will create some degree of competitiveness at a national level. However, regulatory authorities lag since most staff may not be trained in these new technological requirements for innovation. Regulation capacities remain weak unless there are knowledge capacities.

Firm 9: KEMRI-Wellcome Trust BioBank (local malaria vaccine – RTS,S/AS01)

The KEMRI-Wellcome Trust Biobank is a vital resource that supports various research projects, including screening for Malaria, HIV, SARSCoV2 and other diseases. It limits the severity of diseases by offering a platform for drug development using epigenetics and precision medicine for local populations, thereby contributing to harm reduction. Currently, Malaria accounts for an estimated 1 to 3 million deaths each year, with the majority occurring in children under five years of age in Sub-Saharan Africa. Kenya has been selected as a site for the RTS,S Malaria Vaccine Implementation Programme (MVIP) to assess to assess the feasibility of administering the vaccine, its potential impact on mortality rates and its safety profile. From mid-2018 to 2020, in line with national and international regulations, the safety profile of RTS,S/AS01's would continue to be monitored during its phased introduction. The vaccine is being administered in Western Kenya's sub-counties (WHO, 2020). The project employs red biotechnology in the development of the vaccines. Its niche development dynamics are as shown in Table 9.

Table 9 KEMRI-WELLCOME Trust Biobank (local malaria vaccine – RTS,S/AS01) niche innovation dynamics

	Firm 9: KEMRI-WELLCOME Trust Biobank (local malaria vaccine – RTS,S/AS01)	
Bioeconomy principles involved	Red Biotechnology for instance, where lab prepared antibodies are combined for vaccine preparation	
Niche development and competitiveness implications	Developed in a sheltered place for incubation.	*Yes:* Vaccines and drugs are developed in well-equipped labs to control for most variables that may affect their quality and safety. Testing is always done in controlled animal facilities and later in clinical trials that are carefully monitored before the competent authorities can approve the products for use by the general public.

Table 9 KEMRI-WELLCOME Trust Biobank (local malaria vaccine – RTS,S/AS01) niche innovation dynamics (continued)

	Firm 9: KEMRI-WELLCOME Trust Biobank (local malaria vaccine – RTS,S/AS01)	
Niche development and competitiveness implications	Possibility for continuous evaluation and incremental improvement.	*Yes:* Several stakeholders are involved in the development of, e.g., vaccines. These are the small biotech companies such as BioNtech, Curevac and Oxford. Clinical trials and large-scale manufacturing have been carried out by the large pharma companies in collaboration with local communities where vaccines will be tested, research scientists, relevant governments, and health authorities.
	Exhibited temporal increasing returns or learning economies.	*Yes:* For drugs and vaccines, they undergo extensive testing in phase 1 to 3 in a chronological manner. An improvement must be observed at each stage before moving to the next stage and before the product is finally released to the general public once all the set standards are met.
	Still open to development in different directions.	*Yes:* Vaccine development often uses a vaccine delivery vehicle called a viral vector packaged with the necessary ingredients for a particular vaccine to be delivered to humans. The viral vectors can be improved and used to deliver several other vaccines to humans or even animals. Improving the viral vectors can enhance better vaccine efficacy. The potential use of one viral vector for several different vaccines, as well as vaccine adjuvants is possible.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*Yes:* The pros and cons of the drug or vaccines are considered, and approval is only granted for human use when the benefits outweigh the adverse or negative effects with marginal side effects.

Firm 10: Pona herbs limited (biosynthesis and product development)

Pona Herbs Limited is one of the firms based in Kenya's coastal region, developing medicinal products targeting specific diseases. The founder, Dr. Amos Lewa Mwavita is a pharmacist doubling as a research scientist at KEMRI. Among other products, the firm has developed *Virad*, an anti-HIV drug and *Anti-VirH*, an anti-Covid-19 drug. Although the former was patented by Kenyatta University, Pona Herbs Limited were involved in its development. The second product is registered as a utility model at KIPI and licensed by the Ministry of Health through the Pharmacy and Poisons Board. These two products have immunity-boosting and virus mitigating actions.

The convergence of computing and life sciences provides various applications, using biosensors and bio-compounds, enabling rapid identification of specific micro-organisms. Such progress allows increasingly sophisticated *in vitro* or *in silico* investigations to be

carried out at the molecular level, thereby reducing the need for animal testing (Mehrotra, 2016). Pona Herbs Limited is now exploring biosynthesis strategies in their product development in partnership with the United States International University (USIU), among other partners. These steps would allow for faster and cheaper identification of target molecules and increase the pace of clinical trials. The firm uses employing red biotechnology for medical/chemical applications along the biomedical and clinical research spectrum. Its niche development dynamics are as shown in Table 10.

Table 10 Pona herbs (biosynthesis and biosimilar development) niche innovation dynamics

	Firm 10: Pona herbs (biosynthesis and biosimilar development)	
Bioeconomy principles involved	Red biotechnology for the medical/chemical applications.	
Niche development and competitiveness implications	Developed in a sheltered place for incubation	*No:* While the firm has not enjoyed formal incubation in an established incubator, it has leveraged its networks to seek necessary support for its growth. These include KEMRI, USIU and True Pharmacare. It is currently negotiating support from companies from Ontario.
	Possibility for continuous evaluation and incremental improvement.	*Yes:* Many improvements could be made, but these would require additional tools and equipment, which they do not have at this time. These include extraction tools that could be used to extract compounds from plant materials.
	Exhibited temporal increasing returns or learning economies.	*Yes:* For example, the *anti-VirH* has caught the attention of the Cabinet Secretary of the Ministry of Health and they are in discussion to have improvements, especially on the equipment being used, are underway. Such political goodwill has been achieved due to increased bottom-up recognition of their efforts.
	Still open to development in different directions.	*Yes:* Quality product development is the firm's primary focus at this time, followed by scaling up and increased distributions in the region. There are recognised markets and networks in South Africa and Zambia and establishing a community of practice that would lead to for these products gaining in acceptability in the region would be useful. The expertise for product development exists, but there is limited infrastructure.
	Already attractive to use for certain applications in which the disadvantages of the new technology are of less importance and the advantages are highly valued.	*No:* Increasing attractiveness has lagged because validating anything within the national regulatory frameworks and systems is resource intensive. For instance, certification from the Pharmacy and Poisons Board (PPB) cost KES 120,000 (≈US$ 1,200) took 6 months. In the US, it would cost ≈ US$100 and would take about 1 week. In addition, clinical experts do not often recommend alternative organic products, which is a significant handicap to their growth. However, word-of-mouth recommendations in the community are increasing their visibility.

5 Discussions and conclusions

Although the potential extent and scale of the impact, both direct and indirect, of biological innovations remains very significant (Gatune et al., 2021), the bioeconomy discourse has placed a major focus on agricultural and environmental considerations, with rather rare reference to the health and biopharmaceutical domains. While to 60% of the physical inputs into the global economy could be produced biologically, currently only about a third of these inputs are biological materials. The remaining is non-biological materials but could, in principle, be produced using innovative biological processes (McKinsey Global Institute, 2020).

Demand factors for a health bioeconomy comprise the need for high quality and affordable diagnostic and biopharmaceutical products, including medicines and vaccines, and a reduced dependency on development partners by creating in-house solutions for diseases and epidemics. Other macro-level conditions include establishing a national health system that targets universal health coverage and addressing the United Nations' 3rd Sustainable Development Goal on improved health through new and refined therapy forms. We focused on the first two demand conditions to explore how secondary disease prevention through the knowledge-based bioeconomy paradigm can contribute to sustainable niche development. In a feedback loop, these would influence the production factors, including enhancing education and capacity building as well as the creation of biotechnology knowledge (see Figure 2) to produce complex innovations at the meso-level.

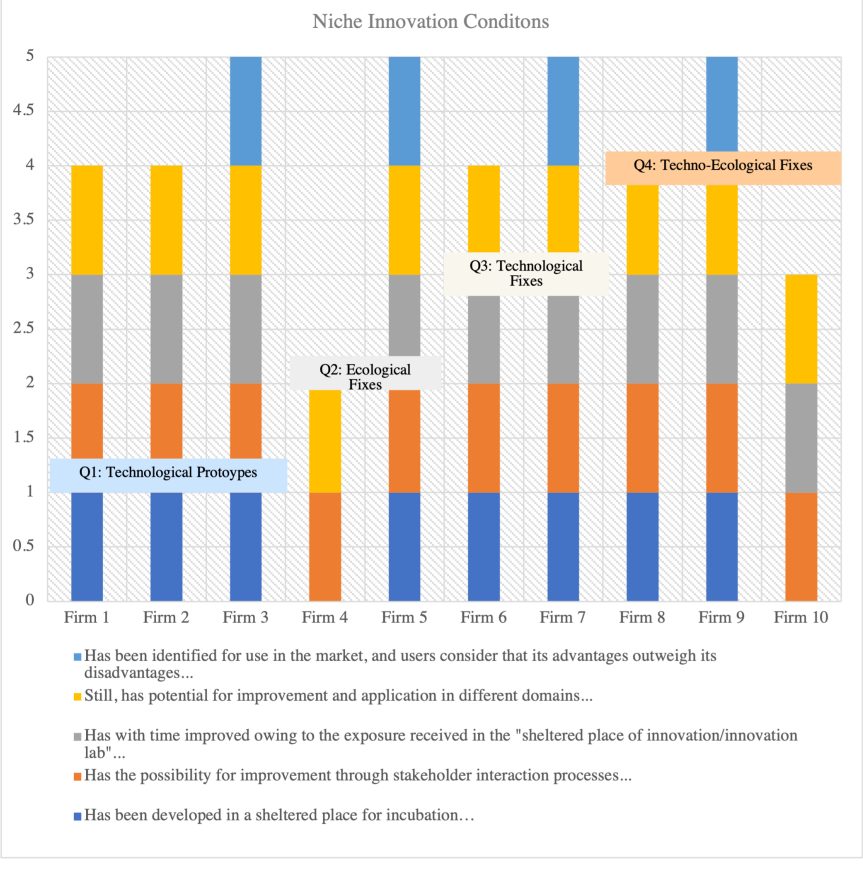
The contribution made by the case studies discussed herein to the knowledge-based health bioeconomy presents clear pathways for addressing health demands. The individual contributions of the quadrant-specific innovations illustrate how these are configured to address environmental conditions in the bioeconomy and how niche innovation conditions allow them to leverage on technological and knowledge advancements. The niche innovation conditions are present in all the quadrants (see Table 11), but are lowest in the ecological-fix innovations, particularly in the case of Firm4. This confirms that niche development allows innovations to increase the internalisation of environmental conditions, thereby enrolling in nature's real subsumption. Firm5-Zion Herbal is unique in that the founder has made a deliberate effort to forge collaborative partnerships with incubation hubs and innovation system actors (see Figure 7), acting as an advocate for increased investment in ecological-flix innovations. This finding supports what was empirically demonstrated in a set of Iranian firms, i.e., those firms that combine indigenous R&D with technological collaborations through niches make most progress in capacity building (Ahmady and Mehralian, 2020).

Entrepreneurial leadership stands out as a distinguishing factor for the indigenous resource-based firms (Upadhyaya and McCormick, 2020). This is seen in the case of Firm5-Zion Herbal that has enjoyed significant exposure, as was also the case for Firm4-Sahrec Enterprises. Other traditional medicine herbal healers in Kenya have been unable to afford the advantages of incubation and participation in the niche dynamics that other firms enjoy. Many of them are so wary of the intentions of 'techno-advanced' partners that they do not benefit from product improvements, which hinders their participation in the formal health systems. This supports findings from a set of biotechnology firms in Estonia, governance mechanisms issues override the intention to leverage synergies and specialisations between small start-up firms and established R&D firms (Kirs, 2016).

Table 11 Percentage contribution to full niche conditions per quadrant

		Average	*Percentage contribution to full niche conditions*
1	Technological prototype	0.866666667	27%
2	Ecological fixes	0.7	21%
3	Technological fixes	0.9	28%
4	Techno-economic fixes	0.8	24%
		3.266666667	100%

Figure 7 Niche innovation conditions (see online version for colours)



Using the pre-identified niche criterion, mapping done on niche development in the bioeconomy confirms the hypothesis that secondary preventive medicine interventions in HIV and Malaria constitute a niche for the bioeconomy (Caniëls and Romijn, 2008). These innovations leveraged on niche conditions to advance their development for market acceptability, as seen by the advantage taken by Firm5-Zion Herbal vis-à-vis its counterpart Firm4-Sahrec Enterprises. Niche conditions allow for variability, all Firms confirmed that there is still have potential for improvement and further applications in

different domains. Improvement can also be achieved through stakeholder interaction processes.

The first quadrant presents technological prototypes, here Ilara Health and Matibabu device, both high-tech reliant innovations. They represent 27% of full niche conditions except that they have not been approved by regulatory authorities for use in the market as they are still in the development phase.

However, in the case of 'techno-ecological fixes' firms that would have otherwise been classified as indigenous knowledge rent-seekers such as Firm10-Pona Herbs are taking advantage of niche innovation network dynamics to afford taking advantage of innovation institutions such as KIPI. Their activities, albeit at a slow pace, continue to resemble those of established 'techno-ecological fix' firms such as Firm8-CREATES.

Still, infrastructural challenges exist for techno-ecological fixes, seen where Firm10-Pona Herbs has potential to leverage regional networks and expertise but nonetheless faces such challenges. Dedicated incubation systems can help such firms leverage platform technologies to advance their innovations. These latter set of firms have a more refined understanding of 'bioeconomy principles' (c.f. Figure 6). They link their health bioeconomy actions to what Mittra (2015) describes as the new biology, participating in applying innovation policy in health and the bioeconomy to meet health and sustainable growth challenges. This way, patients benefit from improved translation of health research into new drugs and better care.

Therefore, we propose that policy interventions allow 'ecological-fix' innovations to tap into existing and future technological knowledge. We also propose that 'technological-fix' innovations participate more in bioeconomy discourses as they have a significant role to play in the configurations proposed through emergent bioeconomy policies.

Declaration of interest

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

References

Ahmady, R. and Mehralian, G. (2020) 'Technological capability building in Iranian biosimilar industry', *International Journal of Technological Learning, Innovation and Development*, Vol. 12, No. 4, pp.251–266, Inderscience Publishers, doi: 10.1504/IJTLID.2020.112739.

Amin, A.A. et al. (2007) 'The challenges of changing national malaria drug policy to artemisinin-based combinations in Kenya', *Malaria Journal*, Vol. 6,s doi: 10.1186/1475-2875-6-72.

Birch, K., Levidow, L. and Papaioannou, T. (2010) 'Sustainable capital? The neoliberalization of nature and knowledge in the European 'knowledge-based bio-economy'', *Sustainability*, Vol. 2, No. 9, pp.2898–2918, doi: 10.3390/su2092898.

Caniëls, M.C.J. and Romijn, H.A. (2008) 'Strategic niche management: towards a policy tool for sustainable development', *Technology Analysis and Strategic Management*, Vol. 20, No. 2, pp.245–266, doi: 10.1080/09537320701711264.

Chouchana, L. et al. (2020) 'Dolutegravir and neural tube defects: a new insight', *The Lancet Infectious Diseases*, pp.405–406, Lancet Publishing Group, doi: 10.1016/S1473-3099(20)30117-1.

Devaney, L. and Henchion, M. (2018) 'Consensus, caveats and conditions: International learnings for bioeconomy development', *Journal of Cleaner Production*, Vol. 174, pp.1400–1411, Elsevier Ltd, doi: 10.1016/j.jclepro.2017.11.047.

Dutta, S., Lanvin, B. and Wunsch-Vincent, S. (2019) 'Global Innovation Index 2019', *Organización Mundial de la Propiedad Intelectual* [online] https://www.globalinnovationindex.org/gii-2016-report# (accessed 20 September 2021).

Frings, M. et al. (2018) 'Modeling and mapping the burden of disease in Kenya', *Scientific Reports*, Vol. 8, No. 1, pp.1–9, Nature Publishing Group, doi: 10.1038/s41598-018-28266-4.

Gatch, M.B. et al. (2013) 'The HIV antiretroviral drug efavirenz has LSD-like properties', *Neuropsychopharmacology*, Vol. 38, No. 12, pp.2373–2384, doi: 10.1038/npp.2013.135.

Gatune, J., Ozor, N. and Oriama, R. (2021) 'Modelling bioeconomy futures for Eastern Africa', *Foresight*, Emerald Group Holdings Ltd, doi: 10.1108/FS-03-2020-0032.

Golembiewski, B., Sick, N. and Bröring, S. (2015) 'The emerging research landscape on bioeconomy: what has been done so far and what is essential from a technology and innovation management perspective?', *Innovative Food Science and Emerging Technologies*, pp.308–317, doi: 10.1016/j.ifset.2015.03.006.

Institute for Health Metrics and Evaluation (2019) *Kenya | Institute for Health Metrics and Evaluation* [online] http://www.healthdata.org/kenya (accessed 16 February 2020).

International Advisory Council of the Global Bioeconomy Summit 2018 – IAC-GBC (2018) *Global Bioeconomy Summit Conference Report. Innovation in the Global Bioeconomy for Sustainable and Inclusive Transformation and Wellbeing*, p.108 [online] https://gbs2018.com /fileadmin/gbs2018/GBS_2018_Report_web.pdf (accessed 17 February 2020).

Jadotte, Y.T. et al. (2019) 'The emerging identity of the preventive medicine specialty: a model for the population health transition', *American Journal of Preventive Medicine*, Vol. 56, No. 4, pp.614–621, Elsevier Inc., doi: 10.1016/j.amepre.2018.10.031.

Kenya National Bureau of Statistics (2019) *Economic Survey 2019*.

Kirs, M. (2016) 'Expansion of science-based industries: technological and organisational accumulation vs. fragmentation? Insights from biotechnology in Estonia', *International Journal of Technological Learning, Innovation and Development*, Vol. 8, No. 4, pp.303–344, Inderscience Publishers, doi: 10.1504/IJTLID.2016.081705.

Mahomoodally, M.F. (2013) 'Traditional medicines in Africa: an appraisal of ten potent African medicinal plants', *Evidence-based Complementary and Alternative Medicine*, doi: 10.1155/2013/617459.

McKinsey Global Institute (2020) *The Bio Revolution, Innovations Transforming Economies, Societies, and Our Lives* [online] https://www.mckinsey.com/~/media/McKinsey/Industries /PharmaceuticalsandMedicalProducts/OurInsights/TheBioRevolutionInnovationstransforming economiessocietiesandourlives/MGI_The BioRevolution_Report_May 2020.ashx (accessed 17 February 2020).

Mehrotra, P. (2016) 'Biosensors and their applications – a review', *Journal of Oral Biology and Craniofacial Research*, pp.153–159, Elsevier B.V., doi: 10.1016/j.jobcr.2015.12.002.

Mittra, J. (2015) *The New Health Bioeconomy: R&D Policy and Innovation for the Twenty-First Century*, doi: 10.1057/9781137430526.

Mittra, J. and Zoukas, G. (2019) 'Unpacking the concept of bioeconomy: problems of definition, measurement, and the attribution of 'value'', *Science and Technology Studies*, Vol. 20, No. 10, pp.1–20 [online] file:///E:/Videos/Downloads/69662-Article Text-114360-1-10-20190227.pdf (accessed 17 February 2020).

Mugo, P.M. et al. (2017) 'Uptake and acceptability of oral HIV self-testing among community pharmacy clients in Kenya: a feasibility study', *PLoS ONE, Public Library of Science*, Vol. 12, No. 1, doi: 10.1371/journal.pone.0170868.

Musuva, A. et al. (2017) 'The malaria testing and treatment landscape in Kenya: results from a nationally representative survey among the public and private sector in 2016', *Malaria Journal*, Vol. 16, No. 1, p.494, doi: 10.1186/s12936-017-2089-0.

Nkala, O. (2018) 'Kenya bans use of HIV drug Dolutegravir by pregnant and breastfeeding women', *Outbreak News Today* [online] http://outbreaknewstoday.com/kenya-bans-use-hiv-drug-dolutegravir-pregnant-breastfeeding-women-96287/ (accessed 7 March 2021).

Phillips, A.N. et al. (2019) 'Risks and benefits of dolutegravir-based antiretroviral drug regimens in sub-Saharan Africa: a modelling study', *The Lancet HIV*, Vol. 6, No. 2, pp.e116–e127, Elsevier Ltd, doi: 10.1016/S2352-3018(18)30317-5.

Pyka, A. and Prettner, K. (2017) 'Economic growth, development, and innovation: The transformation towards a knowledge-based bioeconomy', *Bioeconomy: Shaping the Transition to a Sustainable, Biobased Economy*, pp.329–340, doi: 10.1007/978-3-319-68152-8_11.

STEPS Centre (no date) *Methods Vignettes: Sociotechnical Imaginaries, Pathways to Sustainability* [online] https://steps-centre.org/pathways-methods-vignettes/methods-vignettes-sociotechnical-imaginaries/ (accessed 13 July 2021).

The International Conference on Primary Health Care (1978) Declaration of Alma-Ata.

Upadhyaya, R. and McCormick, D. (2020) 'Entrepreneurial capabilities of successful firms: a study of small and medium-scale equipment manufacturers in Nairobi, Kenya', *International Journal of Technological Learning, Innovation and Development*, Vol. 12, No. 3, pp.169–190, Inderscience Publishers, doi: 10.1504/IJTLID.2020.112226.

Vivien, F.D. et al. (2019) 'The hijacking of the bioeconomy', *Ecological Economics*, December, Vol. 159, pp.189–197, Elsevier, doi: 10.1016/j.ecolecon.2019.01.027.

WHO (2020) *Malaria vaccine pilot launched in Ghana | WHO | Regional Office for Africa* [online] https://www.afro.who.int/news/malaria-vaccine-pilot-africa-one-year-new-vaccine-could-boost-kenyas-malaria-fight (accessed 28 February 2021).

Wield, D. et al. (2013) 'Twenty-first century bioeconomy: global challenges of biological knowledge for health and agriculture', *Science and Public Policy*, doi: 10.1093/scipol/scs116.

World Health Organisation (1948) *Constitution of the World Health Organisation: Principles*, WHO.

Appendix

Table 12 Percentage of disease incidence reported in health facilities, 2014–2018

	2014	*2015*	*2016*	*2017*	*2018*
Diseases of the respiratory system	38.30	39.80	38.70	34.20	39.30
Malaria	20.50	16.70	16.40	18.80	19.40
Diseases of the skin (incl. ulcers)	9.70	10.40	8.70	7.70	7.90
Diarrheal diseases	6.40	6.80	5.70	6.10	5.50
Urinary tract infections	2.90	3.40	3.30	3.70	3.90
Pneumonia	3.20	3.30	3.20	2.90	3.20
Accidents (incl. fractures, burns etc.)	2.30	2.50	2.60	2.70	2.80
Rheumatism, joint pains, etc.	2.90	3.20	3.10	2.90	3.30
Intestinal worms	0.80	0.70	1.50	1.80	2.10
Eye infection/condition	2.10	2.20	2.00	1.60	1.70
All other diseases	10.90	11.10	14.90	17.60	10.80
TOTAL	100.00	100.10	100.10	100.00	99.90

Source: Kenya Economic Survey 2019

Table 13 Kenya's health competitiveness ranking 2019 in Indicators 5 and 6, GII 2019

		SCORE	*RANK*
5	Business sophistication	32.2	61
5.1	Knowledge workers	26.3	[92]
5.2	Innovation linkages	45.0	20
5.3	Knowledge absorption	25.2	100
6	Knowledge and technology outputs.	20.1	72
6.1	Knowledge creation	11.3	65
6.2	Knowledge impact	30.4	92
6.3	Knowledge diffusion	18.5	57

Source: Global Innovation Index 2019 (Dutta et al., 2019)