Chapter

Biomimicry, Big Data and Artificial Intelligence for a Dynamic Climate Change Management Policy Regime

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Abstract

The adverse impacts of climate change are not always immediately discernible. Managing the impacts of this dynamic phenomenon demands an equally dynamic policy regime instead of the traditional and often static policy response mechanisms. The traditional policy responses are often a result of long consultative processes sometimes stretching over several years. Frequently, this generates obsolete policy responses. In this chapter, we propose the development of a dynamic policy and legislation formulation and implementation system that respond to dynamic disturbances such as climate change. The proposal draws from natural systems that have been constantly evolving over aeons. The proposed approach uses the systems lens of biomimicry positing that lessons from natural systems can be mimicked using models that rely on artificial intelligence (AI) to monitor changes through analysing and learning from Big Data and utilising rapid feedback loops to subsequently self-improve policy response mechanisms. Hypothetically under this approach, some key indicators for climate change and related hazards, exposure, risks and vulnerability can be tracked and material policy changes automatically made to appropriately to mitigate and/or adapt to climate change thus avoiding the pitfalls of the traditional protracted policy change routes.

Keywords: climate change, policy, biomimicry, Big Data, artificial intelligence

1. Introduction and background

Despite the near universally acknowledged, observed and predicted adverse impacts of climate change, a quandary in this space is the slow and inadequate policy and practice set of responses in climate change mitigation and climate change adaptation practices. One would expect a global and intense focus on managing the adverse impacts of this phenomenon across and between all governments, the private sector and virtually all of humanity. However, this is not the case. This is because managing climate change is a complex and continuous process whose effectiveness is determined by the actions of diverse groups of individuals, communities, governments, local and international agencies all with a wide variety and, very often, conflicting agendas. Nevertheless, the scope and sophistication of policies and practices seeking to manage the various aspects of climate change continues to advance. The management of climate change manifests through the dual policy approach that employs either/or and often both the market-based and the regulatory mechanisms of climate change management.

Market-based mechanisms involve creating economic instruments to direct the flow of finance, technology and capacity-building support towards innovations and actions that mitigate greenhouse gas (GHG) emissions to retard global warming and ultimately climate change [1]. The mechanisms are rooted in economic principles that seek to heighten the frugality of managing climate change through activities that do not compromise the efficacy of the embedded mechanisms. Two popular mechanisms under the market approach are the Kyoto Protocol rooted in the Clean Development Mechanism (CDM) and the International Emissions Trading (IET) [1]. The regulatory mechanisms, also called the command-and-control policies, invariably require polluters to take specific actions to reduce emissions [2]. Typically, these actions comprise the installation of particular technologies seeking to meet specific environmental management performance standards, that is, GHG emission reduction. While academics, policymakers and bureaucrats often make a distinction between these mechanisms, practice shows an overlap between the two. In fact, and largely, the two are mutually inclusive.

Although there is link between interventions related to climate change and economic indicators, there are other important indicators such as biodiversity that are difficult and perhaps not necessary to reduce to absolute monetary terms. For example, about 40% of the global economy relies on biological products, and 35% of the total jobs are dependent on ecosystem services that support sectors such as agriculture, construction, forestry, textiles and tourism [3, 4]. This indicates the complexity of variables that need consideration in any effective and efficient strategy for managing climate change. Such management, its related policies and legislation need to balance the economic, social and environmental approaches. What is important in the irrespective approaches is the timely provision of relevant data and information about potential hazards and potential benefits of climate change, globally and in specific locations. This is critical to deliver appropriate, adequate and well-timed responses. Such a delivery system equally demands a rapid, flexible and dynamic policy formulation, implementation and revision system. An important input to this system is relevant, adequate and accurate (as much as possible) data to enable the development of appropriate policies. Policymaking based on such data is the essence of evidence-based policymaking. The basis of evidence-based policymaking in the public policy space is the quest to anchor social reform programmes on pertinent and practical knowledge provided by scientific research [5]. This approach elevates the importance of collecting and analysing the appropriate and adequate amount of data, both qualitatively and quantitatively.

A traditional complaint around managing climate change, climate change adaptation in particular has been the paucity of relevant quantities of data for processing to derive trustworthy information. However, this condition has and continues to improve rapidly and definitely. A combination of rapid and incessant increases, and improvements in the sophistication, affordability, compactness and use of technology are enabling the prompt generation and analysis of copious data sets. These large sets of both structured and unstructured heterogeneous data are known as Big Data. In principle, the timely (often in real time) processing of this data accompanied by appropriate policy responses can make a difference between the ability to rapidly as well as suitably respond to the climate change hazards and costly policy reform delays.

A challenge in the policy arena is that outside absolute dictatorships, contemporary and 'acceptable' policy formulation, adoption and implementation processes follow a routinely lengthy bureaucratic and linear approach. These processes often exclude the views of one or other concerned group(s) through a typical accentuating of internal bargaining among small, highly placed powerful groups [6]. Actors in the policy space bargain around their personal beliefs and preferences as well as those of interest groups they represent. These beliefs and preferences may initially vary widely but are narrowed by the give-and-take practices of the bargaining process. Consequently, the policy outcomes of the process rarely advance the absolute views of single individuals but instead are a mix of views from several individuals [6]. While this is the essence of democracy, the disadvantage is that the nature of bargaining processes usually delivers suboptimal policy outcomes and often belatedly. While the importance of democracy in policymaking is acceptable, the delivery of suboptimal and delayed policy responses is problematic in dealing with dynamic and deleterious effects of phenomena such as climate change, economic development and human health, among others. Ideally, the desired policy responses must be dynamic, and more importantly, they must deliver systemic changes for efficient policy implementation, monitoring and evaluation that may lead to either to policy entrenchment or revision.

Nature is replete with forms of order and seemingly systemic changes in large complex systems. In principle, the policy formulation, implementation and revision space can draw important lessons from the collective and individual units of biological systems such as cell colonies, schools of fish, ant colonies and bird flocks. A protuberant characteristic of collective behaviour in such natural systems is the appearance of global order in which individuals harmonise their states to an extent of giving a striking impression that the group behaves as one [7]. While it is posited that group formations in systems such as insect swarms are a mere epiphenomenon of the independent interaction of each individual with an external landmark and stimuli, what matters is that the resultant order remains impressive and individual actions culminate in a collective benefit. While group formations are impressive, nature also shows deeper and long-lasting systemic changes that confer adaptation of individuals and entire ecosystems to external conditions.

Looking at how nature both rapidly and gradually but systemically adjusts to a plethora of stimuli and eventually achieves a ‘dynamic equilibrium’, it is arguable that managing climate change, that is, adjusting both mitigation and adaptation strategies and regimes, can learn from biological systems. A timeous and appropriate adjustment of relevant policy levers is critical for managing climate change. To this end, this chapter proposes a dynamic policy based on a learning, self-improving and self-adjusting policymaking approach that draws lessons from biological systems and it components—the essence of biomimicry. Ideally, the proposed approach was appropriate and should seek to avoid the lengthy policy cycle stages but still deliver a systemic and responsive policy to manage climate change narrowly and sustainable development broadly. The suggested and futuristic policymaking approach is cognisant of the fact that there is limited clarity around the concept of global order in many biological systems. It is also aware of fears around artificial intelligence/machine-learning phenomena as well as the contests and power dynamics in the policymaking space. Nevertheless, we posit that lessons from how natural systems both as individual and most relevantly as a system have and still evolve to adapt to changing environmental conditions carry important learning points for the proposed policymaking approach. As stated earlier changes in natural systems are both immediate as in the case of a school of fish avoiding predators and slow, for example, how the ecosystems have adapted to ionising radiation from Chernobyl [8]. Even slower is that birds of flight have evolved to have hollow bones strengthened by struts to reduce dead weight, whereas flightless birds like ostrich have more solid bones. In the case of birds of flights, bones in places with higher stresses are more solid. This principle informs the building of the shells of modern aircraft to optimise weight and strength of designs. Eliminating unrequired material means less dead weight, less fuel consumption and thus a lesser carbon footprint. Indeed Mother Nature can be a model, measure and mentor.

2. Methodology

The need for the proposed dynamic policy model arises from a process of critical reflection focusing on policymaking and adjusting to unpredictable phenomena—climate change in this case. The reflection draws from the biggest teacher of survival tactics under challenging, unpredictable and dynamic conditions—Mother Nature.

As a methodology, critical reflection informs on ways that improve practice. It involves the ability to unearth, examine and change firmly entrenched assumptions leading to central changes in perspectives [9]. In seeking to challenge established positions and change them, critical reflection pays attention to the power dimensions of assumptive thinking. It examines how power dimensions affect the envisaged or proposed changes that may deliver desired outcomes [10]. In this chapter, the focus is challenging some tenets of the policy cycle arguing that in making or amending policy, not all components of a policy need to go through the cycle. Some important technical components can avoid the cycle if the policymaking process has mechanism to analyse and interpret relevant data that has a bearing on policy specifics, that is, codes and standards. This is the essence of the proposed learning and self-adjusting policy. In principle, such a policy can deliver an optimal policy regime provided the adjustments are driven by adequate and appropriate data.

Four traditions of thinking guide critical reflection as applied here. The first is reflexivity. This relates to how a researcher is aware of biases of analytic focus on his or her relationship to the field of study and the ways that cultural practices involve consciousness and commentary on themselves [11]. In this research, it was important to be reflexive considering our experiences as authors specifically as researchers, practitioners and concerned citizens in the climate change, sustainable development and broader social development spaces. Also important is our preference for the trans-, inter- and multidisciplinary research—a desirable approach in the sustainable development discourse. As a result, the concepts that inform the proposed policymaking approach are eclectic drawing from climate change, policymaking, biological science and computer technology. This reflects our academic training, experiences and practice.

A second consideration is reflective practice. This pertains to an awareness of the gap between theory and practice [12]. As authors, we are aware of this, often with first-hand experience on observing policymaking and its implementation and sometimes lack of implementation because of power dynamics in the policy space. The third component of critical reflection is deconstructionism. This relates to questioning the notion of generating knowledge in a progressive and nonconflictual manner [13]. Critical reflection interrogates power relations and in this case questions (and even threatens) the role of politicians, lobbyists and public service bureaucrats in the policy cycle. The fourth and final tradition of thinking in this methodology is critical social theory. Its importance to the arguments in this chapter is the argument that the use and interpretation of knowledge are social constructed [10]. This means it is possible to change or improve the same knowledge as well as its use and interpretation. This is important as the proposed model involves the use of artificial intelligence—a largely feared and in some cases a politically unpopular practice [14].

Despites these and other advantages, critical reflection also has weaknesses. Among the many weaknesses, a relevant one is that reflection is centred on individuals and not groups. Proposing a new approach to policymaking that in some cases eliminates the human element may not be everyone's cup of tea. Nevertheless, we advance such a model noting the urgency of policies that rapidly react to both the present and potential drivers and adverse impacts of climate change avoiding some sometimes misplaced human reluctances to deal with the problem head-on. Now, it is important to emphasise that we are not in any way suggesting humans make a wholesale delegation of their role to technology. Instead, we seek to improve policymaking for the benefit of humanity, and technology has a role in that endeavour. In advancing this view, a glimpse into the dynamics of policymaking is critical.

3. Conventional policymaking

Policies are essentially government or private organisation statements of what these entities intend to do or not to do, including laws, regulations and decisions designed to achieve defined goals [15]. Public policies essentially are government statements that outline public plans of dealing with societal problems in terms of the relevant laws, regulations or orders that seeks to influence behaviour for long-term societal collective benefits [15]. However, despite stating their objectives and the enacting of laws, public policies in particular are often late and regularly deliver suboptimal outcomes. Such outcomes and associated delays result from compromises that are necessary to accommodate the diverse views of critical and powerful/influential stakeholders active in the policymaking arena. With reference to public policy, the outcomes reflect the prevailing political system. The policy cycle is a conceptual model that outlines the formulation, implementation and revision of these plans [3, 16, 17]. The cycle comprises five political activities, namely, (i) agenda setting, (ii) policy formulation, (iii) policy adoption, (iv) implementation and (v) evaluation.

Agenda setting deals with selecting societal problems that require addressing through public policy interventions. Such problems could be local issues such as discernible crime levels, public transport concerns or global issues such environmental degradation and international trade and standards. Power dynamics and asymmetries in the cultural, political, social, economic or ideological arenas are important for either including or excluding societal issues in and from policy agendas [18, 19]. This implies that some important societal problems may not make it to the policy agenda especially those not championed by powerful constituencies as individuals and/or groups of elected or bureaucracy public officials, the media and the interest groups [18, 20]. An issue that makes it to the policy agenda then proceeds to the next process of policy formulation. This is the stage at which discussions seek to define the courses of action for dealing with particular societal challenges.

The related discussions take place in government bureaucracies, legislative bodies (i.e. parliament) interest group offices and public meetings, that is, special commissions, among other platforms [21]. Visible activities of policymaking inter alia include parliamentary debates, exchange between parliament and the executive and public policy enquiries. Power dynamics remain in play at this stage. For example, interest groups may work with the executive, parliament or even the senior civil servants to formulate policy. Some parliamentary representatives may owe the success of their campaigns to the financial backing of interest groups who expert particular policy positions as a return on their investment. This approach excludes other groups that may have different interests and views on the policy agenda. After policy formulation, policy adoption, which essentially is the official recognition of a policy, follows. This essentially is an exclusive domain of explicit actions of government institutions. Adoption is dependent on the majority of relevant actors such as parliamentarians, either as individuals, representatives of particular groups or along party lines accepting the proposed policy [22]. The political systems play an important role in the policy adoption process. Absolute dictatorship, veto or other forms of executive powers can be used either to accept or reject a policy as earlier formulated or with modifications.

Accepted policies proceed to the implementation stage with the conversion of new laws and programmes into practice. A critical component of public policy implementation is capable and capacitated civil service in the bureaucratic structures of government. Implementation involves the interpretation of policy documents into operational frameworks. To this end, there is a need of clarity of policy objectives particularly where are the contestations around a particular. Ambiguity and conflict result in policy implementation challenges [23]. In addition, an accurate translation of policy documents into operational frameworks avoids the bureaucratic drift phenomenon [24], which is the shifting of policy away from its objective and towards the preference of the bureaucracy. After a period of implementation, it becomes necessary to evaluate the efficacy of the policy. This serves to ascertain if or not a policy has or is attaining its stated objectives. Evaluation examines if a policy has resulted in changes in practices and behaviours, satisfied needs such as increasing financial savings, addressing traffic congestion or addressing environmental concerns or has systematically addressed core societal problems and not mere symptoms of the problem(s). More important is that evaluation serves as feedback mechanism to either modify the existing policy for improved efficacy and identifying new challenges that in turn enter the policy cycle commencing with agenda setting. This gives rise to an interminable policy cycle. Alternatively, policy evaluation can lead to the termination of some policies.

The journey from agenda setting to policy adoption can be long. For example, in the international arena, the contribution of different countries in mitigating GHG is a hotly contested issue. The glimmer of hope that emerged after the Paris Agreement (COP 21) has somewhat been extinguished by the Donald Trump administration in the United States of America. Meanwhile GHG emissions continue to grow and with that global warming and ultimately climate change with its adverse impacts. In an ideal world, climate change needs the rapid development of a policy regime that manages climate change. More importantly, the policy must be evidence-driven and be flexible to rapid changes as dictated by emerging knowledge. Even more important is that the policy regime must confer systemic changes. This is a tall order in a globe with diverse interests and views. Nature often delivers on systemic changes that deliver widespread optimal outcome. Can policymaking learn from nature?

4. Biomimicry and climate change

The growing severity of the impacts of climate change demands a rapid and vast array of policy actions that both mitigate and adapt humanity and indeed all other flora and fauna to the impacts of these changes. The focus of mitigation is reducing or eliminating the increase of anthropogenic GHG emissions into the atmosphere. Adaption seeks to assist the world live with the inevitable climate change adverse events arising from global warming due to historic and present high GHG emissions. The question for many who seek to manage the climate change challenge is how to navigate the highly contested mitigation and adaptation policy and practice space. Contestations in this arena arise because managing climate change carries a mix political, economic and environment considerations around which humans rarely share similar views concerning the best options in maximising utility.

As debates continue, contestation sharpen and diminish, there is a growing focus on how humans can emulate nature's ability to heal itself as well as to adapt to environments both harsh and otherwise. This mimicking is the essence of the science of biomimicry. The term biomimicry emerges from a combination of the word *bios*, meaning life, and *mimesis*, meaning to imitate. Biomimicry is a discipline that studies nature's strategies and how humans can emulate these strategies to solve contemporary challenges in a sustainable manner. Benyus captures the essence of biomimicry stating:

The core idea is that nature, imaginative by necessity, has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers. They have found what works, what is appropriate, and most important, what lasts here on Earth. After 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival [25].

The essence of this assertion is that nature is replete with examples that can inform human activities, in this case on climate change mitigation and adaptation. This biomimicry operates in three distinct but interlinked levels of (i) organism level mimicry, which mimics a specific organism; (ii) the behaviour level, which focuses on how an organism behaves to its larger environment and (iii) ecosystem level mimicry [26].

An example of organism level biomimicry is that of the Teatro del Agua outdoor theatre in the Canary Islands, which mimics the Namib desert beetle *Stenocara* in condensing moisture in sea breeze to generate fresh water that is collected and used in this theatre [27]. The focus of behaviour level biomimicry is not the organism per se but rather how that organism behaves in changing both the biotic and abiotic material and systems in its environment [26, 28, 29]. For example, the behaviour of the North American beaver (*Castor canadensis*) of blocking water flow in rivers creates wetlands that retain nutrients, which in turn leads a diversity in both the resident flora and fauna generating a resilient ecosystem [30].

While mimicking individual organisms or their behaviour may benefit efforts seeking to manage climate change, greater benefits accrue if the mimicry is systemic, that is, it covers an entire ecosystem. This approach is concerned with how systems in all individual organisms, the environment and its resources work and interact as a collective. Any important theoretical construct of the ecosystem level biomimicry is the ecosystem principle. The principles (**Table 1**) are an overly simplified representation of how ecosystems operate.

An important point from the table is that an ecosystem is a function of all individual organisms in a locale, their behaviour as individuals and relative to other organisms both of their kind and not of their kind within that system. More important and relevant to this chapter is the point that ecosystems seek to optimise the entire system rather than its components. This is important because it many mean that one component of the system may have to compromise its individual absolute efficiency to deliver a system-wide optimal outcome. The key to such an outcome is using limited resources only for functions that are critical and leaving the rest for others to do the same [4]. Mjimba [31] refers to such an approach as the concept of separating real needs and wants in redefining a new path to sustainable development.

Mimicking ecosystems can focus on both the function and process strategies of ecosystems. The functions of ecosystems relate to services that include the provision of food and medicines, soil formation, detoxification of gases and liquids and climate regulation, among others [32]. The focus on process strategies relates to ecosystem aspects that confer resilience to these systems. This pertains to how ecosystems work both at individual and collective levels, the inherent relationships in the system with the related feedback loops that deliver the capacity and capability of an ecosystem to self-correct and self-heal [4].

Ecosystem principle	Ecosystem components
Ecosystems are dependent on sunlight	Energy is drawn from sunlight The sun carries spatial and time management means
Ecosystems optimise the system and not its individual components	Matter is cycled Energy is transformed Materials and energy are applied for multiple functions
Ecosystems carry various apparatuses, associations and information	Diversity enables resilience Relationships are complex and are arranged and work in varied hierarchies There is complementarity and cooperation in ecosystems Ecosystems are subject to emerging trends and events Ecosystems self-organise
Ecosystems are in harmony to and hinge on local conditions	Ecosystems often use local materials Ecosystems exploit locally available and abundant prospects
Ecosystems adapt and evolve	The rates and levels of ecosystem adaptation and evolution differ Ecosystem are in a constant flux of a balanced non-equilibrium Ecosystems self-correct and self-heal
Ecosystems create conditions that sustain life	Functional ecosystems enhance biospheres Ecosystem functions and outputs are environmentally benevolent

Source: Pedersen and Storey [28].

Table 1.
Ecosystem principles.

An understanding of the theories of evolution and/or adapting suggests that the self-correction and self-healing manoeuvres of an ecosystem make use of past and present data such as the weather (i.e. temperature, humidity and wind currents) to ensure that the ecosystem remains optimal. An analogous situation to such adjustments is the behaviour of animals like fish, birds and locusts moving in large numbers.

Moving group of such animals have to balance the need (or nature) to maintain close proximity simultaneously with their ability to change both direction and speed as a unit while avoiding colliding with both other group members and physical structures in their environment [7, 33]. This type of behaviour resides in the biological driven response of the individual animals, which manifest as a self-organised system [7]. The formations of these self-organised systems differ between and within the different types of birds, fish or insects as determined by the reasons for their movement and the population size of the group. For instance, in birds, a turn may or may not result in changes in the shape, density and volume of the flock and the positions individual birds take up in the flock [7]. Similarly, schools of fish change their formations based on the size of the schools. Very large schools of up to and more than 10,000 fish have subformations within the entire group. The entire school formations and its subformations change in response to predators and other external influences [33]. An important and relevant observation is that the reaction of individuals that actually sense either danger or an opportunity triggers similar reactions by other group members that may not have sensed the hazard or opportunity [33]. Humans too sometimes conform to this coordinated collective behaviour [34]. For example, the etiquette on the escalators up or down the City of London underground railway network is that as the escalator moves one can stand on the right-hand side and walk on the left-hand side. Largely this enhances the overall human traffic movement efficiency by decreasing the number of movements to avoid collisions. This is also apparent in the flows of people moving in opposite directions in a street or other constricted spaces. Often the people extemporaneously organise themselves into lanes of uniform walking direction to enhance easier movement. What is interesting is that such arrangements develop without particular individuals either managing or broadcasting these activities or relevant information about them so that others may follow.

In all these forms of self-organised systems, the observed changes are (often) systemic and seek to optimise efficiencies for the entire system rather than its components. This is different from the aforementioned compromises that deliver suboptimal outcome in the conventional policymaking process of democratic societies. Another important feature of such systems is their ability to receive data continually, process this data to generate information that triggers adjustments that deliver rapid changes again seeking at attaining (eventually) optimal outcomes for the systems. Based on these and other observation propose the development of a policymaking machinery that learns and self-adjusts. Such machinery would be appropriate for managing some aspects of dynamic challenges such as those of climate change. This proposal rests on using recent technological developments to drive some aspects of policymaking. We focus on two developments here, Big Data and artificial intelligence, and use these to propose a biomimicry-based policy cycle model for managing the challenges presented by the climate change phenomenon.

5. Artificial intelligence, Big Data and dynamic policy: Policies inspired by natural systems

Before we proceed to the model, a minor detour is inevitable as a foundation for the proposal. This detour briefly outlines the concept of artificial intelligence (AI). A growing discussion in the world of computer science is around the types of computer intelligence. Terms that include, cognitive computing, machine learning and deep learning, are the focus of this chapter around artificial intelligence (AI). Often, there is an interchangeable use of these terms in daily language. However, the terms differ although refer to related things.

Cognitive computing refers to the sensory subdivision of machine intelligence that is used. Sensors and algorithms are used to enable computer to 'see', 'hear' and 'feel' [35]. Through image sensors computers can see, microphones facilitate their hearing ability and the text-to-speech and speech-to-text technologies permit computers to interconnect with humans using natural (human) language through programmes such as Alexa, Siri, Cortana and Google Assistant.

Simplified, machine learning is knowledge computers gain from old data and historical trends identifying patterns that humans cannot identify [36]. This form of machine intelligence uses colossal amounts of data to generate patterns recognised by computers and thereafter used to differentiate objects from each other, for example, distinguishing between male and female humans or cats and dogs including the different breeds of these animals. The deep learning branch of machine intelligence involves using neural networks that mimic the physiology and function of the human brain [36, 37]. The networks include several layers of neurons that permit computers to learn from historical data and thereafter apply in a way similar to how a human brain thinks [36]. This is the most advanced form of machine learning which is increasingly becoming the favoured approach in training computers.

AI refers to machines acting in ways that seem intelligent [35]. This is through enabling decision-making capabilities to computers. The intention of AI is for computers to make decisions that address specific problems just as humans do every day [35]. Computers use recommendation engines for this purpose, whereas narrow AI is a machine-based system designed to address a specific problem such predicting election results [15, 35, 37]. AI applications work in several branches that include machine learning, natural language processing and robotics. Our proposal is to extend the application of AI into the policymaking space to inform climate change mitigation and adaptation based on models adapted from natural systems through the process of biomimicry. This is a proposal for a dynamic policymaking model. The quintessential proposition of the model is the sequence of quick interventions that incorporate rapid and automated feedback loops that reinforce learning in the policy cycle so that the policy remains in a state of dynamic self-improvement as shown in **Figure 1** (the Mjimba-Sibanda dynamic policy model).

The first stage of the model entails an analysis of natural biological systems using the biomimicry lens in order to understand the strategies that nature has evolved over aeons. The appropriate and relevant strategies are turned into design principles that are no longer limited to the biological context. These general design principles are used to inspire the development of a base policy. To update the policy continually, whenever defined factors change, the abstracted principles are modelled to produce algorithms that mimic the behaviour of the natural biological system, including in terms of having specific variables for the algorithm. The algorithm's input is Big Data from both the public domain and relevant databases for public policy. Artificial intelligence leverages the sensing of relevant data input, computing the historical and live data in order to adjust the policy and to provide feedback to improve the modelling of the algorithm. Most attractive is that computing the Big Data can enable the prediction of future scenarios. In principle, this means avail an opportunity to anticipate future challenges and adjust the policy to avoid or adapt to those changes before they even manifest. Adjusting to avoid such changes is the essence of climate change mitigation, and adjusting to manage the impacts of the changes relates to climate change adaptation- anticipatory adaptation. The desired policy adjustment can either be automatic, which is desirable in some cases, or be an outcome of debates that are characteristic of the democratic policymaking process.

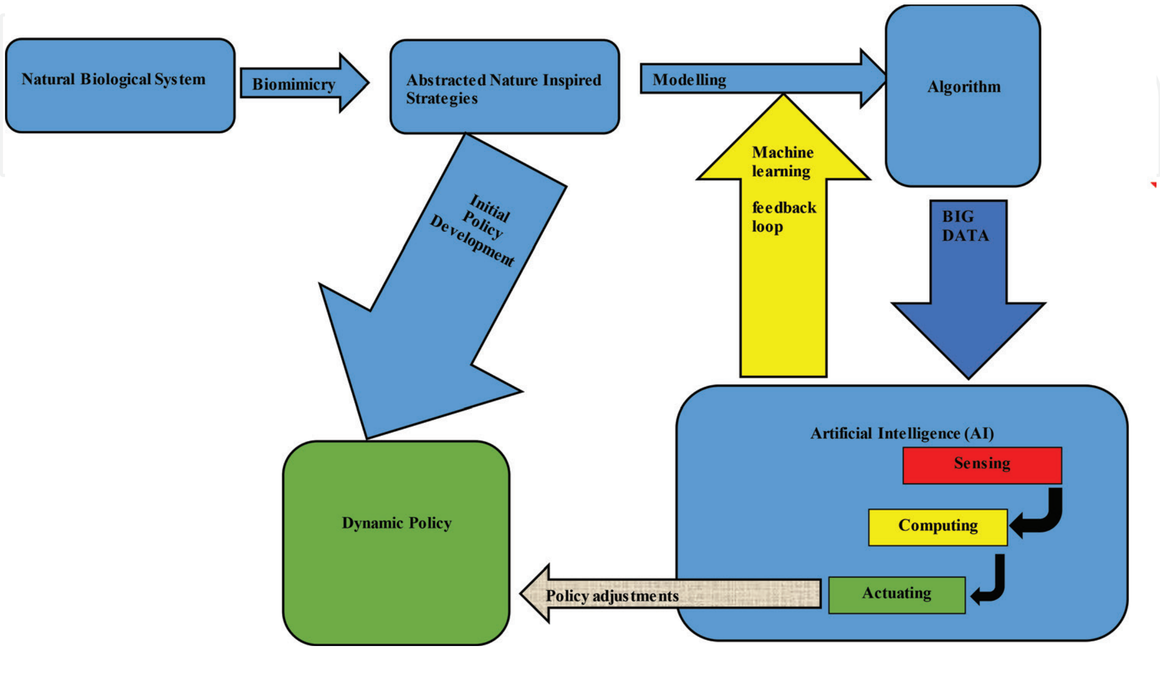

Figure 1.
The Mjimba-Sibanda dynamic policy model. Source: Authors.

6. Applying the model

New ideas and innovations often struggle to gain traction particularly when benefits around them are obscure or disputed both rightly or wrongly. Cognisant of this fact, two examples illustrate plausible applications of the proposed model in both climate change mitigation and climate change adaptation. Before presenting the examples, a brief recap of some tenets of the biomimicry-policymaking nexus that informs the Mjimba-Sibanda dynamic policy model may be in order.

First, it is important to remember that biomimicry applies to three main typologies: mimicking form, process or system. Mimicking form entails emulating (not exact copying) a particular shape in order to achieve a particular function. Second, mimicking a system requires understanding of dynamics of complex interactions. In nature, an ecosystem illustrates such complex system. In natural ecosystems, the concept of waste does not apply because everything is either raw material or food for another and everything is recyclable in a closed resource loop. In such systems, there is co-evolution and co-development. The analogous human concept is the circular economy [38]. The Kalundborg Industrial Park in Denmark illustrates this concept through the co-location of complementary industries that exchange resources that include water, heat, gas, fertiliser and fly ash [39]. Here, we take the view of policy development as being analogous to co-evolving mutualistic relationships in a thriving ecosystem. In that regard, policy development has to seek greater benefits of systems and not components of systems. Let us now revert to the examples of two cases relating to climate change mitigation and adaptation.

Carbon sequestration is a plausible intervention of climate change mitigation. Forests such as the Amazon forests are significant and natural sequestration arenas. However, since the 1970s, over 18% of the Amazon rainforests have been destroyed mainly for agricultural, timber logging and mining, among other activities. This has removed a significant carbon sink. In addition, these forests provide habitat for about a quarter of the world's terrestrial species and account for about 15% of terrestrial photosynthesis, whose by-product is the oxygen that humans and other animals breathe. Part of climate change mitigation seeks to retard and halt the further destruction of these forests. AI can help understand the relationships among various parameters such as rainfall, humidity, wind, temperature and floods. In addition, AI can also project changes in the acreage of critical forests projecting how these changes affect ecosystem services such as carbon sequestration. The relative changes in these parameters can be used for policy modelling seeking to enact automatically more stringent policy and legislation prescripts that can reduce the rate of depletion and promote regeneration of natural forests. The optimisation of natural systems such as the hydrological cycle, natural runoff, percolation and evaporation rates could provide benchmarks for what ideal conditions policy may seek to foster. An advantage of applying the proposed model in such a scenario is that the policy relies on both current and predicted possible conditions based on current deforestation rates. In addition, the generation of stringent conditions relies less on human judgement with AI generating the interrelations among species and components and, most important, making specific policy adjustments seeking to halt or mitigate present and future hazards.

Regarding climate change adaptation, machine intelligence such as AI and machine learning can predict possible future scenarios including the timing of their manifestation. Big Data fed into machine learning could help predict, for example, the areas with the likelihood of coastal flooding associated with climate change-related sea level rises. A dynamic policy could prescribe future actions such as land rezoning to stop further construction or the introduction of new building codes in areas with highest exposure to natural hazards and high probability of such risks manifesting. Similarly, the policy could define insurance models and levels of disaster preparedness triggered automatically should sea levels reach specified thresholds. This would enable various groups such as residents, investors, insurance providers and emergency services such as the police, hospitals and disaster units to be better prepared.

At first glance, the two examples may appear far-fetched and impractical. However, the plethora of late but well-intended and sometimes incoherent policies in many disciplines suggest that a systemic and self-adjusting policy regime is ideal to deal with the dynamics and nuances of issues such climate change. This holds in majority of policies that relate to climate change adaptation. Traditionally, these have often appeared after adverse events have occurred, instead of manifesting pre-the event to minimise damage. Even in the mitigation drive, the various actions arguably react to events that are avoidable, that is, driving reforestation instead of avoiding deforestation. The Mjimba-Sibanda dynamic policy model seeks to avoid this by taking a proactive policy approach to managing climate change. The approach takes the 'evidence-based' policymaking position by using large amounts of data to change both timeously and appropriately the relevant policy standards, codes and other parameters. The advantages of such dynamic policies are available elsewhere. Although the advantages do not necessarily use machine learning and do not draw from biomimicry, they nevertheless apply in this argument.

One important example of dynamic policy is in Kenya. Following the disputed 2007 elections, the feuding parties in the country eventually agreed to a negotiated settlement that culminated in a Government of National Unity (GNU) that comprised representatives of the various political parties. The political parties designed reforms for a more democratic political dispensation. Due to the prevailing mistrust at the time, the parties agreed that the implementation of the new Constitution, which came into effect in 2010, would include self-executing mechanisms. For example, certain provisions that required the President to ratify Bills by a specific date were set to become the responsibility of the Chief Justice if the President did not act accordingly. Similarly, if the Chief Justice reneged in signing the same within a defined period, the said provisions could automatically become law. Compelled by these conditions, on 27 August 2011 the then President signed 15 out of 27 Bills that were to meet the 1-year deadline [40]. Elsewhere, and using computer technology, the development of the blockchain-based smart contracts phenomenon offers interesting cases for the proposed Mjimba-Sibanda model. A blockchain is a distributed data structure replicated and shared among the members of a network [41]. Smart contracts are instruments that coded to automatically execute when certain criteria are met [41]. Merging the blockchain and smart contracts innovations gives rise to decentralised self-executing and self-enforcing contracts. Similarly, the proposed Mjimba-Sibanda model envisages future-oriented self-executing mechanisms aiming to manage climate change. Its criteria for executing changes will be a continuous computation of biological, climatic, physical and other data to generate policy that drives best practice concerning both climate change mitigation and adaptation.

7. Conclusion

Tying it all up, it is important to note that the current state of affairs in the management of climate change is in part because of human frailties in the process of making policy that can respond effectively to this challenge. Most concerning in this regard is that sometimes humans are reluctant to take decisions that may interrupt established but destructive practices and adopt new and seemingly inconvenient practices that may present long-term benefits. In addition, sometimes humans struggle to gather, analyse and link varied and vast amounts of data to generate information that appropriately informs policy and practice. This condition extends to many disciplines of social and economic development. The Mjimba-Sibanda dynamic policy model seeks to avoid some of these human shortcomings. The model proposes to combine lessons from biological systems, with the new concepts of Big Data and machine learning/artificial intelligence to define critical policy components that can aid the management of climate change.

As stated earlier nature learns and adapts both in the short and long terms. Mother Nature is the biggest teacher on earth. Through biomimicry, humans learn to emulate nature both at individual and system levels. However, lessons from nature are numerous and nuanced to an extent that the human mind may not adequately decipher the relations in these lessons. Modern computer technology serves to address this shortcoming, and the rise of artificial intelligence, especially machine learning, among other related concepts, offers an opportunity for improved decision-making to improve human conditions on earth. At this point it is important to allay fears of machines taking over the human-decision function.

Our belief is that humans working with machines, each contributing what it is good at, can produce outcomes that are much better than when humans and machines working separately. Furthermore, our position is that even in democratic societies, there are policy shifts that need to, can and must avoid the bargaining vagaries of the policy cycle and shift automatically when the relevant and adequate amounts of data accurately and appropriately generates credible information to develop fair, transparent and equitable policies. This is important in an environment which data generation and analysis are happening with greater speeds, the severity and frequency of climate change-linked extreme weather events are increasing and political expediency is sometimes overriding genuine environmental concerns with long-term detrimental effects. In such a scenario, rapid and to an extent automatic policy shifts are important. What is critical is that automatic changes in one area or department should in turn trigger relevant policy changes across government departments, private, public sectors and industries to deliver a system-wide change that avoids policy incoherencies and conflicts. Where human intervention can override machine decisions, the process should be transparent to all relevant stakeholders to prevent abuse by those with the overriding capability and authority. More important is that all overrides must always leave an auditable and public trail log of who effected the changes and the corresponding rationale.

The journey towards a new policymaking approach begins!

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