Representation and Intervention Constructs for SDG Localisation

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***Abstract*—Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, are presented as a blueprint for our world's social, economic, and environmental progress. The SDGs have a structured framework spread across 17 goals, 169 targets and 232 unique indicators. The socio-economic, and demographic challenges and opportunities are not uniform for all nations. Hence, the agenda of SDG localisation encourages all member states of the UN to establish and customize suitable national frameworks to localise the 17 interlinked goals following their domestic factors. However, SDG localisation requires conceptualising the key concepts of sustainability and sustainable development. An absence of a suitable representation framework makes it challenging to represent, reason, and compare disparate methods and schemes adopted for SDG localisation. In our work, we address modelling challenges for representing and reasoning around sustainability. We argue that sustainability is a "state of being" making it a *state-maintenance* problem, rather than a goal-achievement problem. Our central principle around sustainability extends Amartya Sen's capability approach which states that the well-being of people should be understood in terms of people's capabilities and their functionings. We add sustainability as a separate dimension, asking how resilient a given set of capabilities are and thus propose SDG indicators to be interpreted as *capability* indicators. Hence, both the sustainability and capabilities of a state need to be maximised to maintain or improve the indicators. Therefore, *sustainable development* is defined as achieving capability targets and their progressive sustenance.**

***Index Terms*—sustainability, SDG, stress, capability**

I. Introduction

Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, succeeded the Millennium Development Goals (2000-2015) that focused on poverty eradication, better health care for infants and mothers, and combating life-threatening diseases predominantly in the economically deprived countries[1]. The SDGs extended to and embodied 17 goals[2] with 169 targets and 232 unique indicators with a vision to address the social, economic and environmental concerns that universally apply to all. With the agenda of SDG localisation, the UN encourages countries to adopt global targets based on their national priorities and challenges and implement them at the local levels in collaboration with the sub-national and regional governments and authorities. This includes having specific SDG indicators at state, province (block), sub-block, and village levels, ranking and rewarding them based on SDG scores, and performing interventions for low-performing or "aspirational" regions[3]. SDG localisation can also help in mainstreaming the granular issues and aligning Environmental, Social, and Governance (ESG)-based investment decisions[4].

However, we find the SDG approach to be overtly reductionist, and sometimes in conflict with cultural practices around sustainability– a concept that already has deep roots in the cultural psyche in different parts of the world[5]. The SDG approach is pursued as a "goal-oriented" activity, geared towards the achievement of specific targets and indicators along different verticals. This is a characteristic paradigm of manufacturing or production activity. At the same time, conventional worldviews towards sustainability see it as a problem of *preservation*– which is of the nature of *state maintenance*, rather than the achievement of targets.

Abstract notions of sustainability and capability have been central conceptual instruments in areas like developmental economics, political science, and in systems analysis and design [8], [11], [14], [17], [19], [20]. Indeed, sustainability is seen as a guiding principle for social justice, replacing "market forces" as the ultimate arbiter of fairness in free societies [13], [15]. But to the best of our knowledge, there is so far, no systematic approach to include these crucial concepts for representation and reasoning around sustainability in conjunction with capabilities.

We address several such challenges by re-framing SDG targets as *capability targets* rather than sustainability targets. This is an extension of Amartya Sen's *Capability Approach* which emphasizes that the well-being of people should be understood in terms of people's capabilities and their functionings [21].

Hence, we present a hermeneutic framework to represent and reason around sustainability based on our ongoing work for designing policy interventions for promoting sustainability [3]–[5], [12].

[1]https://www.who.int/news-room/fact-sheets/detail/millennium-development-goals-(mdgs)
[2]UN SDGs https://sdgs.un.org/goals
[3]https://www.niti.gov.in/india-policy-insights
[4]https://www.undp.org/governance/sdg-localization
[5]https://www.weforum.org/agenda/2017/10/what-india-can-teach-the-world-about-sustainability/

II. Literature Review

The UN has adopted the three pillars of sustainable development namely social, economic and environmental as the baseline for achieving sustainability. The pillars, introduced by Barbier [2], are often represented as three intersecting circles with sustainability at their centre. Hence, the present concept of sustainable development is held synonymous with the idea of sustainability that corresponds to achieving the goal of sustainability by the process of sustainable development [10]. We discuss different viewpoints on the idea of sustainability and its related concept, sustainable development, and contrast them with fresh perspectives on the subject of sustainability presented in Section III.

The most widely cited definition of sustainability is taken from the Brundtland Commission report [7] of 1987 which states sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". However, Costanza et al. [9] refer to [7] and argue that what passes as the 'definitions' of sustainability, are essentially predictive assertions. They go on to define a sustainable system as one that attains its full expected life span in the nested hierarchy of systems within which it is embedded. Ben-Eli [6] also criticises the prevailing definitions [7] as vague, and one that does not offer any clear operational guidelines. The author argues since future generations can not participate in deciding what might be best for them, the definition is flawed from the viewpoint of process. The author defines sustainability from a system's perspective as "a dynamic equilibrium in the process of interaction between a population and the carrying capacity of its environment such that the population develops to express its full potential without producing irreversible adverse effects on the carrying capacity of the environment upon which it depends". Walker et al. [23] discuss the meaning of sustainability depending on three attributes for sustainability scenarios - resilience, adaptability and transformability for social-ecological systems (SES). The authors define resilience as "the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks". The authors add, that adaptability being part of resilience is the capacity of the actors in a system to influence resilience. Transformability is the capacity to create fundamentally a new system when the ecological, economic, social or political conditions make the system untenable.

The state of sustainability mentioned by Costanza et al. [9] as a system that persists is true but we disagree with definitions that define sustainability as a function of time. Most SES systems operate in open, uncertain environments, making it impractical to use longevity as a basis for reasoning. Instead, we argue that the sustainability of a system can be discerned by its resilience against environmental perturbations. We define the sustainability of a systemic state as the *magnitude of perturbation* required to dislodge the system from its current state and make it settle down in a new state. We develop this approach in detail, by proposing a logic of "being" in section IV.

III. Understanding Sustainability

The UN-SDG approach to sustainability largely interprets sustainable development as a problem of provision of basic assurances. For instance, poverty is defined as living below US$1.25 a day, and hunger is calibrated based on the Food Insecurity Experience Scale (FIES) defined by the UN's Food and Agricultural Organization (FAO)[6]. However, sustainability is an abstract principle, that applies to any complex system of being– even to powerful and wealthier populations and organizations. For instance, major corporations like Nokia and Nortel Networks underwent crises of sustainability, when the technological landscape around them changed. Addressing sustainability as an abstract characteristic of any kind of system is important because sustainability considerations are often interdependent. The sustainability of basic assurances may depend on the sustainability of larger, more powerful institutions, and vice versa. As discussed in Section II, we present some fresh perspectives to understand the concept of sustainability:

- As argued by Constanza and Patten [9], sustainability cannot be interpreted as a target. Every statement about sustainability is essentially an *assertion or hypothesis about the future* that how sustainable a given configuration of the system is likely to be. The sustainability of a given system and in a given configuration (interpreted in terms of longevity) is largely evident only in retrospect, and all a priori statements about sustainability are essentially hypotheses. We can only know after the fact, how sustainable was the state of the system.
- Sustainability is also not a "goal" to be achieved. The question of sustainability remains even after the capability is achieved. Hence, sustainability targets are better interpreted as *capability* targets and sustainability is better modelled as a "state-maintenance problem" rather than a goal-achievement problem.
- Sustainability is also not a binary attribute, with a true or false value. When we assert that a specific configuration is sustainable, it does not mean that the system would be sustained in that state permanently. No physical entity sustains forever. Some states may be more sustainable than others, and we need to reason about sustainability in degrees, rather than with logical truth or falsity.
- Sustainability considerations of individuals and that of the collective can also conflict. Constanza and Patten [9] provide an example of improving the longevity of individuals pursued as a means of promoting their sustainability. A large population of individuals all of whom have high levels of longevity will also, however, pose a much higher demand on resources and consumption, which may end up challenging the sustainability of the population as a whole.

[6]FIES:https://www.fao.org/in-action/voices-of-the-hungry/fies/en/

TABLE I
UNDERSTANDING SUSTAINABILITY FROM MULTIPLE PERSPECTIVES

Perspective	Meaning
Not a goal	Sustainability is not a “goal achievement” problem but a “state-maintenance” problem
No binary logic	Sustainability is a matter of degrees and not a predicate with crisp semantics
Only retrospective verification in the open world	Statements on sustainability are not predictive but retrospective
Context sensitivity	Changing the environment may change the sustainability of a state
Conflict between individual and collective	Improving individual sustainability may affect collective sustainability
Not a virtue by itself	The most sustainable states may also be the least desirable states of the system

- Similarly, sustainability is not an attribute of a system in itself, but an attribute of the interaction of various systems with their environment. For instance, a thriving and stable economy located amid economic instability in its surrounding vicinity will also start facing sustainability crises due to the instability in its environment.
- Finally, the state of sustainability is not always virtuous in itself. For example, it is much easier to sustain a state of poverty, than to sustain a state of newly acquired wealth. Sustainability needs to be investigated along with an abstract notion of *capability*, and both variables need to be maximised together. It can be argued that *sustainable development* means *sustainable improvement of capabilities*.

We argue goals and targets are relevant for capability improvement, and not for sustainability itself. Much of the SDG targets are better interpreted as *capability* targets, rather than *sustainability* targets. For instance, ending extreme poverty or hunger in any part of the world improves overall human capability, but whether it will necessarily lead to a sustainable society, is an independent question. Indeed, what we need is to figure out how to reach and *sustain* a given target like, of no extreme poverty or hunger in any part of the world rather than asserting that the target itself leads to sustainability. The question of sustainability remains even after an SDG target has been achieved.

A summary of all the above-mentioned points is given in Table I.

IV. A LOGIC OF ‘BEING’

To help represent and reason about sustainability and capability, we introduce a framework of modelling and representation. We start by first representing the system of interest (like a country, state, province, etc. whose sustainability we are concerned with) as a “system of being” or simply, “being” [22].

A system of being represents a collection of interacting elements that have one or more invariant properties. The concept of a “being” can be contrasted with *machines* and *chaos*. Machines are systems built for specific purposes, with controlled dynamics that are largely linear, open-loop interactions. On the other end, chaos represents non-linear complex interactions that are sensitive to initial conditions. In between linear machines and non-linear chaos are complex, non-linear systems that we call “beings”. Unlike machines, the dynamics of beings are complex, emergent and intractable; but unlike chaos, beings are *resilient*, rather than *sensitive* to initial conditions. Beings are characterized by one or more stable states of being, which they settle down into. While small perturbations can drive a chaotic system into vastly different outcomes– with beings, small perturbations tend to bring the being back to its stable state.

Formally, let a be a being (either an individual or a collective), that can be in different *states* of being. Let the set of all states of a be represented as $S(a)$. For a given state $s \in S(a)$, the term $d(s)$ represents the “sustainability” of this state s. This is defined as the magnitude of perturbation that is required to dislodge the being from state s such that it settles down into some other state of being. The notion of perturbation is defined in an abstract manner which may take on different forms depending on the context. For our purposes, the magnitude of perturbation is normalized to lie in the interval $[0, 1]$. Hence, $d(s) \in [0, 1]$.

A given state s' where $d(s') = 1$ represents a “sink” state or a *maximally sustainable* state from which the being cannot be dislodged with any magnitude of the perturbation. Typically, such states may not be very desirable (for instance, a state of death of a being).

We divide this section into four parts to better understand the notion of sustainability and the modelling and representation framework from various perspectives:

A. Notion of Sustainability from Being’s Perspective

As noted earlier in Section III, the state of sustainability is not a virtue in itself. Hence, sustainability has to be reasoned in conjunction with an abstract notion of *capability*. For a given state s, the term $c(s)$ represents the *capability* of the being in state s. While the exact definition of capability may depend on the context, for this framework, we define capability as a normalized m-dimensional vector of values from $[0, 1]^m$. As we strive to maximise sustainability, we need to also ensure the maximisation of capability and its sustenance thereof. Hence, the sustainability problem for a being may be defined as:

$$\arg\max_{s} L(d(s), c(s)) \tag{1}$$

where $L(.,.)$ represents a suitable “norm” function that converts the vector-valued objective function into a scalar.

However, as also noted in the previous section, the sustainability of a being is not just a function of its internal characteristics but also depends on the environment in which the being is interacting. For a being a, we use the term $V(a)$ to represent the environment with which the being interacts with.

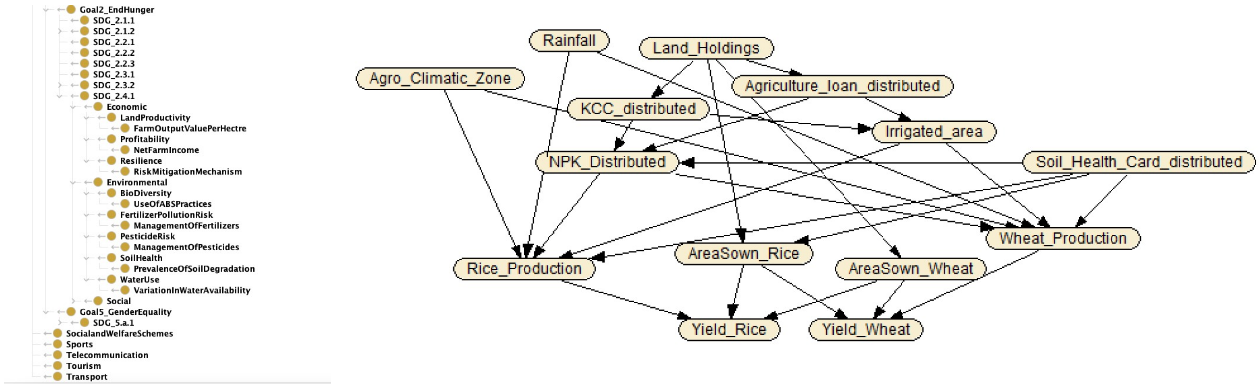

Fig. 1. (a) Taxonomy for SDG indicator and (b) Bayesian network of Crop Yield target

The environment may comprise any number of other objects and beings, but we consider this set to be finite.

B. Notion of Sustainability when Being is part of the Environment

The interaction between a being and its environment is said to result in a "game" where both the being and the environment strive to maximise their interests, through this interaction. As long as the number of ways of interactions is finite, such a game is guaranteed to have a state of Nash equilibrium [16], representing a state of mutual best responses between the being and the environment.

For any interaction between a being a and its environment $V(a)$, we use the term $e(a, V(a))$, to denote a pair of states representing the *mutual best-response* or the *Nash equilibrium* of the game between a and $V(a)$. Given the demands of one's environment, a being is compelled to respond and change into a suitable state of response. The response of the being may, in turn, induce a further response from the environment until this interaction settles down into a mutual best response configuration or equilibrium. When the context $V(a)$ is evident, we use the term $e(a)$ to represent the state where the being is compelled to settle down into, given its environment. The terms $d(e(a))$ and $c(e(a))$ now represent the sustainability and capability of the being in its equilibrium state with its environment.

C. Notion of Sustainability from Policymaker's Perspective

Policy intervention towards a system of being can be interpreted as creating a conducive environment where the system of being can sustainably improve its capabilities. In more formal terms, this can now be stated as the following objective function:

$$\arg\max_{V(a)} L[d(e(a)), c(e(a))] \tag{2}$$

In other words, the sustainability problem can be posed as a problem of curating the environment of a being so as to maximise its capabilities and sustainability in the game of its interaction with its environment.

The above formulation represents a *scale invariant* approach to address sustainability and is naturally suitable for SDG Localisation efforts. A being could represent a system of interest at different granularity like a family, community, village, province, country, etc. The environment represents the externalities with which the being interacts.

Given that the exact nature of the "game" between a being and its environment may vary depending on the context, we introduce another abstract principle by which to compute $e(a, V(a))$. In statistical mechanics, it is well known that complex systems of interacting entities are known to settle down into "low-energy" configurations [1]. This is called the *annealing principle*. We use this as a generic guiding principle for finding the equilibrium state between a being and its environment. The low-energy configuration is modelled as a "stress reduction" problem, where stress is defined as the difference in capabilities between a being and a similar entity in its environment.

For a geographical area under consideration, a neighbourhood graph is built by connecting each province or zone with its immediate neighbours. Formally, the neighbourhood graph is represented as an undirected graph $G = (V, E)$, where the nodes V represent the set of "beings" under consideration (provinces, states, zones, etc.). Edges of the form (u, v) represent adjacency where capability changes in one are assumed to impact the other. Let the set of neighbours of a given node v, be defined as $\Gamma(v)$. Each node $v \in V$ is associated with a capability vector $c(v)$ of m dimensions, where the i^{th} dimension is represented as $c_i(v)$.

Policy intervention is modelled using one or more *policy instruments*. The set of all possible policy instruments is represented using the term I. Application of an instrument $i \in I$ for a being a may result in the being reaching a new state. The sustainability and capability of a being a upon application of policy instrument i are given as $d(i(a))$ and $c(i(a))$ respectively.

From the policymaker's perspective, we need a policy instrument that minimises stress and maximises capability improvement across all beings in the system.

Let the term $Stress = \sum_v stress(v)$ denote the overall stress in the system. Similarly, let the term C denote an aggregate vector of capabilities across all beings in the system.

Policy intervention can now be defined as the following objective function:

$$\arg\min_I Stress \tag{3}$$

$$\arg\max_I C \tag{4}$$

In other words, policy intervention is based on choosing a set of policy instruments that minimise overall stress and maximise overall capability across all beings in the system.

Now, for a node v in the system, let a policy intervention result in the change of the capability vector. A change in capabilities for a given node would affect the game between a being and its neighbours. We model the *capability stress* experienced by a node v as:

$$stress(v) = \sum_{\forall u \in \Gamma(v)} L(c(v), c(u)) \tag{5}$$

Here $L(\cdot,\cdot)$ is a suitable norm or distance function that measures the disparity between two vectors. For our purposes, we use L_2 norm or the Euclidean distance between the two vectors and is calculated as:

$$L_2(c(v), c(u)) = \sqrt{\sum_{i=1}^{m} [c_i(v) - c_i(u)]^2} \tag{6}$$

Each node in the network then computes an adjustment to its capability vector based on minimising its stress with its neighbours. The equilibrium or best-response $e(v, \Gamma(v))$ is given as:

$$e(v, \Gamma(v)) = \arg\min_{c(v)} stress(v) \tag{7}$$

The minimisation of stress is implemented as a gradient descent routine. The network is said to have reached a new equilibrium or sustainable state when stress reduction routines converge for all the nodes. Policy interventions in one region also tend to have side effects on adjacent regions, and sustainable improvement of capabilities would require the formulation of policies that consider side effects and push-backs too.

D. Case Study on Policy Intervention in Crop Yields using Logic of Being

We introduce the abstract model introduced in Section IV in a realistic setting for reasoning about sustainability in a large geographical area. We try to improve one of the SDG indicators for a given state that in turn comprises several districts or zones.

Fig. 1(a) shows a taxonomy fragment of SDG indicators for SDG 2 (Zero Hunger). For each target variable, we construct a Bayesian network model based on consultation with domain experts and available documentation such as government reports, articles, journal papers, etc. relevant to the indicator. Fig. 1(b) shows a Bayesian network model constructed for *Crop Yield*. It is a multi-target network that shows various dependent and independent variables that affect the yield of rice and wheat crops. The target variables in the Bayesian network corresponds to the given SDG target 2.4.1 shown in Fig. 1(a). An edge in a network corresponds to a dependency relationship between the two variables. The independent and dependent variables are defined based on literature studies and government reports which results in a hand-crafted Bayesian network for potential causal analysis.

Each geographical area under consideration (like a province, district, state, etc.) is modelled as a being and is associated with it, is a capability vector that can be unrolled into the taxonomy above, with corresponding Bayesian models for each of its indicators. For each zone a that is modelled as a being, its set of neighbours in the neighbourhood graph forms its environment, $V(a)$. For each capability vector of a node, there is a set of Bayesian models that represent each dimension of capability as a function of one or more variables of interest, as shown in Figure 1(b). For the given network, Rice Yield and Wheat Yield are the dimensions of our capability vector.

Policy intervention modelling entails representing a policy decision in terms of changes in one or more variables. Here, we consider one such example:

Fertilisers are essential for overall plant growth, health, and quality. Sufficient amounts of Nitrogen (N), Potassium (K), and Phosphorus (P) are vital soil nutrients for optimum and healthy plant growth. As shown in Figure 1(b), a policy decision mandating an increased consumption or distribution of NPK fertilisers may impact variables such as “rice production” and “wheat production” thus affecting the yield for rice and wheat respectively. A given policy specification may affect multiple such variables in multiple models. Also, there could be variables in common across multiple models. The dataset used for constructing this model is the *Karnataka at a Glance, 2020-21* report[7] that includes data for all the 31 districts of Karnataka. It is a compilation of statistical information from multiple departments of the government such as agriculture, health, education, women and child development, social welfare, housing, energy, etc. This data bank helps in understanding the overall progress of targets and indicators of Sustainable Development Goals at district and sub-district levels on an annual basis. With this, it also aids in the development of Bayesian networks such as the one depicted in Fig. 1(b). Hence, a policy intervention would mathematically translate into *conditioning* of several variables across several models. Conditioning of these variables would propagate changes in variables downstream, leading to some change in the target variable of the respective Bayesian network.

An ACZ is a land area deemed suitable or unsuitable for agricultural practices. Karnataka has been divided into 10

[7]https://kgis.ksrsac.in/kag/

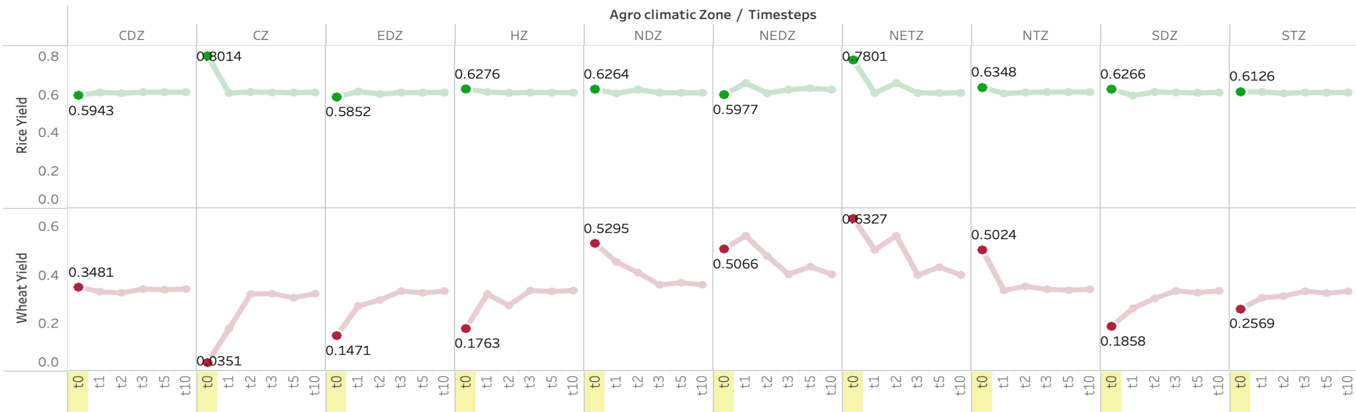

Fig. 2. The figure depicts the normalised values of crop yields *before an intervention* across all 10 Agro-climatic Zones of Karnataka. The yellow-highlighted timesteps point out the values of crop yields at the t_0 timestep.

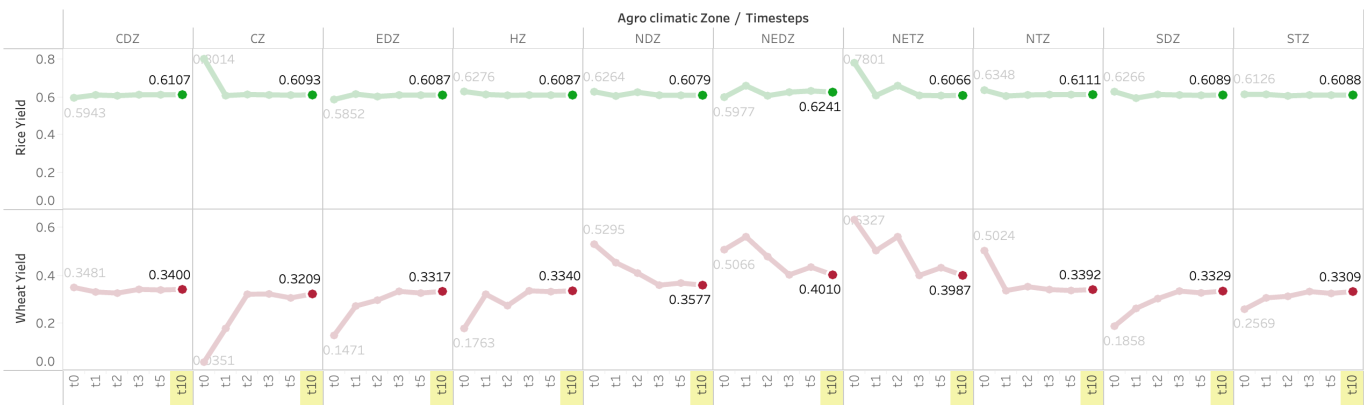

Fig. 3. The figure depicts the impact of high-NPK fertiliser intervention on rice and wheat yields, modelling for 10 consecutive crop cycles across all ACZs Karnataka. The yellow-highlighted timesteps show what the yields settle down to at the 10^{th} crop cycle.

ACZs[8]. The line graphs in Fig. 2 and Fig. 3 represent the normalised crop yield values for over 10 consecutive crop cycles for all the ACZs of Karnataka. In Fig. 2, timestep t_0 is highlighted. It shows the wheat and rice yield values before the *high-NPK* intervention. Fig. 3 shows highlighted values at t_{10} timestep i.e. after the intervention has taken place. Both figures can be compared to understand how the yields of the crops settle down after intervention versus their initial values [18].

It is evident from Fig. 3 that one policy intervention across the state has different effects across neighbouring zones and over different crop cycles for two different crops. Interpretations of such effects are given below:

- The line graphs for rice crops show a neutral impact on the yield inferring a stable intervention. However, the North Eastern Dry Zone (NEDZ), we see a slight spike initially at t_1 (0.65842), which settles down at a lower value at t_{10} (0.6241) indicating a negative impact resulting in an unstable state [18].
- For wheat crops, the Coastal Zone (CZ) shows a spike indicating a positive impact and a stable state. The Northern Dry Zone (NDZ), the North Eastern Dry Zone (NEDZ), and the North Eastern Transition Zone (NETZ) have higher yields as compared to all other zones throughout the stress modelling process. The remaining ACZs have wheat yields settled down at lower values inferring a negative impact of the intervention leading to an unstable state.

[8]https://e-krishiuasb.karnataka.gov.in/Weather/ViewWeatherData.aspx

V. Conclusion

The primary departure we make in this work is to look at sustainability from a holistic perspective and model it as a state-maintenance problem. We see several definitions of sustainability are inadequate to build a robust reasoning framework for SDG Localisation. Hence, goals and targets are modelled as capability metrics rather than sustainability metrics. We understand a policy intervention is a mammoth task to be carried out and the outcomes of which may take several years to manifest. Hence, actual on-ground evaluation is beyond the scope of this work. For the evaluation of our results, we rely on the knowledge, experience and wisdom of domain experts. We hope that the proposed approach enables sustainability-related interventions at any granular level across nations subject to the availability of relevant data. It may also aid corporations invested in crop cultivation or food processing and related stakeholders in identifying areas that require greener initiatives, enhancing digital literacy among the farmer community, and educating them on better yield strategies with ESG investing to engage with local Farmer Production Organisations and Self Help Groups.

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