Self Sufficiency Index (SSI)

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Introduction

As more and more people move into cities, villages are increasingly left behind. One does not need to look internationally to observe the consequences of brain drain; this migration exists domestically as droves of the youth work force relocate to urban hubs while human capital diminishes in the countryside. As this trend continues, villages increasingly become sinks for energy, goods, services, technology, and more, while the city solidifies its role as the source. In other words, the village becomes the consumer; the city, the producer.

An obvious consequence of urban migration is that cities exceed carrying capacities above which the standard of living and quality of life degrade for residents, and the environment is adversely affected from over-extraction. Meanwhile, villages develop greater dependencies on cities. These cities, depending on the region, may be hundreds of kilometers away without the necessary local context to produce relevant solutions. This would be a serious outcome should villages continue to gradually lose the capacity to locally problem solve. In fact, civil rights activist Mahatma Gandhi warned that increasing dependence on external and foreign bodies made rural India vulnerable to exploitation. Traveling the length and breadth of India starting in 1915, however, Gandhi saw promising models for rural development in small community ashrams. These ashrams approached complete self-sufficiency and were effective, productive hubs for reactive governance [16]. These experiences formatively shaped his perception of the village – during Gandhi's time, India was home to around 700,000 villages – as the ideal ecological unit. Rural development was his priority for nation building post-British liberation. Gandhi famously said, "the future of India lies in her villages."

There have been numerous efforts across India to fulfill Gandhi's vision. Examples include the villages of Mandede (population 795) [12] [8] and Pabal (population 3857) [18] [11], both outside of the city of Pune (population 4,569,000) [2]. Mandede and Pabal target carbon neutrality and circular production from the domains of agriculture, energy, water, waste, and services such as education and health. Remarkably, both villages are prone to drought, yet remain at the forefront of self-sufficiency experimentation and research in the country.

However, efforts like these remain largely disjointed and unvalidated, suffering from knowledge fragmentation and the lack of impact metrics. There are no widely adopted metrics in this field for concepts like self-sufficiency. This body of work aims to develop a Self Sufficiency Index (SSI) that can be applied broadly across Indian villages with different geographical, cultural, and sociopolitical contexts as a robust, comparative marker for rural development via a bottom-up approach, from which technology and policy strategies can be drawn and further evaluated.

Ultimately, this body of work views the village as a node in a powerful, distributed system for development. Thus far, the village's potential has largely remained latent. India is a fertile ground to incubate a metric like SSI given its vast network of villages, over 665,000 today [14], and long history of rural self-reliance. Although this work is based on self-sufficiency, its wider contribution and the author's founding motivation are in new development metrics implemented at the village level rather than the national or multi-national level. Largely, policy and organizations established for approaching global climate goals, to take a domain-specific issue as an example, have resulted in directives to national governments and major industries – a top-down approach seen in the Conference of the Parties (COP), the Paris Climate Agreement, and the United Nations Framework Convention on Climate Change (UNFCCC) – that has so-far proven ineffective. Analysis indicates that current global climate practices projected to the end of the century will lead to a 3.2 - 4.4°C increase in temperature by the end of the century, significantly above the 1.5°C target [13]. It is thus reasonable to propose a supplementary bottom-up approach to meeting global climate goals. Such an approach would require suitable evaluation frameworks and impact metrics, a gap in existing work that SSI strives to address. The future may indeed prove that a strategy of collective striving is the answer to the necessary ambitions of our time.

Every metric has an underlying ideology. The Human Development Index

(HDI) [10] used by the United Nations Development Programme (UNDP), for example, considers life expectancy, education, and per capita income over other domains such as community life and civic participation. Here, the development of SSI, currently in its initial stages of formulation, is an exchange not only around methodologies, but fundamentally around the ideologies the metric will reflect.

1 Index General Form

$$SSI = \sqrt[3]{SL \times QL \times \text{Sustainability}} \tag{1}$$

where SL = standard of living, normalized $\in [0, 1]$
QL = quality of life, normalized $\in [0, 1]$
Sustainability(S), normalized $\in [0, 1]$

SSI is a composite index of standard of living (SL), quality of life (QL), and Sustainability (S) (1). SL and QL are standard dimensions in development economics. Using Bérenger and Verdier-Choucane's definition, SL corresponds to commodities, while QL refers to the "functionings" and "capabilities" [1]. Past indicators distinguish SL and QL across objective (e.g. disease incidence rate) and subjective measurements (e.g. an individual's own view of well-being and satisfaction), respectively [15]. In this work, we use objective indicators for SL and a combination of objective and subjective indicators for QL. The sustainability dimension (S) takes into account the past and present to project into the future of the village, asking whether a village that today, maintains SL and QL for its residents, is able to do so reliably over time.

The geometric mean is a common analytical method for capturing compounded effects, seen in international indices such as HDI [10].

1.1 Standard of Living (SL)

SL is measured by taking (current production / total demand) across the domains of nutrition, water, energy, and waste management. Then, we take (current village average / minimum allowable value) for income, health, housing, and education (services and miscellaneous are not measured in terms of production) (2). Note that SL is not measured as a share of (current production / total production potential). Here, SSI acknowledges the potentially diminishing and adverse returns of excess production. Units for each of the above domains are listed in Table 1, noting that the indicator is ultimately unitless after taking the proportion over demand or minimum threshold.

The Classification of Individual Consumption According to Purpose (COICOP), developed by the United Nations Statistics Division, provides an internationally accepted framework for selecting relevant household domains [4]. However, the domains in COICOP far exceed the QL baseline requirements which are considered in this work. Future work can capture household needs in finer resolution using a more complete selection of such macro and micro sectors.

Note that an important consideration for the health domain is whether proximal (direct) or distal (indirect) indicators should be used, e.g. life expectancy and social development, respectively. Moreover, direct indicators of health have historically followed one of two approaches: (a) measuring morbidity, mortality and important precursors of both, or (b) lifestyle and individual behavior [7]. For this reason, no unit has been proposed yet for the health domain.

Table 1: SL domains

domain x	unit	$\gamma^x_{priority}$	$\gamma^x_{d,M}$	$\gamma^x_{d,X}$
Nutrition	kcal/day	–	–	–
Water	L/day	–	–	–
Energy	kWh/day	–	–	–
Waste Management (treatment)	kg/day	–	–	–
Income	income/year	–	–	–
Housing	dwelling size/household	–	–	–
Health	–	–	–	–
Education	gross enrollment ratio	–	–	–

Commonly used notation for this paper include: a set of domains is denoted as D, with any individual domain denoted as $x \in D$; X is shorthand for exports and M for imports; d refers to the distance from the village.

In order to measure demand for the domains of *Nutrition*, *Water*, *Energy*, and *Waste Management*, a feasibility study must first be conducted. In some cases, local production may be unable to meet village demand due to environmental, financial, social, or other considerations. See a sample feasibility study, *200 Guntha Case Study*, for Pabal village in Pune, conducted at Vigyan Ashram campus [18].

$$SL = \sum_{x \in D} \gamma^x_{priority} \left[\frac{x_{\text{local production}}}{x_{demand}} - \gamma^x_{d,M} \frac{x_{\text{remaining demand}}}{x_{\text{demand}}} + \gamma^x_{d,X} \frac{x_{\text{excess production}}}{x_{\text{demand}}} \right] \tag{2}$$

where $\gamma^x_{priority}$ = domain priority weight and $\sum_{x \in I} \gamma^x_{priority} = 1$

$\gamma^x_{d,M}$ represents imports-distance weight $\in (0, 1]$

sample distance-biased weighting scheme:

$$\gamma^x_{d,M} = \begin{cases} 0.2 & \text{if } 0 < d \leq 10\,\text{km} \\ 0.5 & \text{if } 10 < d \leq 50\,\text{km} \\ 0.7 & \text{if } 50 < d \leq 100\,\text{km} \\ 1 & \text{if } d > 100\,\text{km} \end{cases} \tag{3}$$

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sample distance-biased weighting scheme:

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$\gamma^x_{priority}$ reflect local priorities across production sectors. (3) and (4) encourage local imports and exports, should there be shortages or excess in production, respectively.

Our weighting coefficients $\gamma^x_{d,X}$ and $\gamma^x_{d,X}$ indicate that every term in our SL sum ($\sum$) (2) before being weighted by domain priority $\gamma^x_{priority}$ – let's call this value $SL_{x,initial}$ – falls in the range $[-1, 2]$. We want to transform $SL_{x,initial}$'s range from $[-1, 2] \longmapsto [0, 1]$ for simpler normalization when domain priority weighting is applied. Here, we have two options for scaling:

Linear Scaling: $SL_x = \frac{SL_{x,initial}}{3} + \frac{1}{3}$.

Percentile by Gaussian and non-Gaussian Distribution: Here, we take the percentile out of many samples of $SL_{x,initial}$ across an Indian state, say Maharashtra, with the same priorities weighting by domain ($\gamma^x_{priority}$).

We can either assume a normal distribution and take the z-score, where $z = \frac{SL_{x,initial} - \mu}{\sigma}$ to find the normal percentile. Otherwise, without assuming a normal distribution, we can calculate the percentile as $SL_x = \frac{n}{N}$, where n = number of villages below $SL_{x,initial}$, and N = total number of villages assessed. This approach presupposes the availability of data across many villages that is sufficient for deducing SSI, and/or, many villages that have already adopted SSI.

Yet to be addressed in SL is the weighting scheme for the service and miscellaneous domains of income, housing, health, and education. *What is the maximum value of the domain indicator? How are large values normalized? Should a linear proportion be taken? What are equivalent exports and imports, if any?*

1.2 Quality of Life (QL)

QL dimension follows the footsteps of Gross National Happiness (GNH) [17] developed in Bhutan, where we define broad categories and indicators assessed on a threshold basis. by indicators x in the set I:

GNH has nine domains, under which 38 sub-indexes, 72 indicators, and 151 variables are used.

Taking directly from GNH as a baseline (source: 2022 GNH Survey Report, Full Report), we use the following formula:

$$GNH = H^H + (H^U \times A^U_{suff}) \tag{5}$$

where H^H = incidence of happy people
H^U = Incidence of not-yet-happy people, $(H^H)'$
A^U_{suff} = Average sufficiency score among H^U

Domains indexes are then put through an unweighted arithmetic mean. Note that the domains listed in Table 2 are not comprehensive and should be taken only as a sampling. See *GNH and GNH Index, the Centre for Bhutan Studies.*

> The index is aggregated out of 33 clustered (grouped) indicators. Each clustered indicator is further composed of several variables. When unpacked, the 33 clustered indicators have 124 variables, the basic building blocks of GNH Index. Weights attached to variables differ, with

Table 2: QoL indicators, taken from GNH

Indicator	Threshold	Weight	Domain
Knowledge	achieved knowledge score of 19 (assessment)	0.2	Education
Literacy	read and write in one language	0.3	
Schooling	6 years of schooling	0.3	
Values	consider one of five values justifiable	0.2	
Housing	living in housing with roofing, toilet, and room ratio of two	0.33	Living Standards
Household per capita income	above adjusted poverty line	0.33	
Assets	owns at least two appliances or five livestock or five acres of land	0.33	
Mental Health	achieved mental health score of 15 (survey)	0.3	Health
Disability	report having a disability and disability was restricting to their daily activities 'all the time' or 'sometimes'	0.3	
Healthy Days	$\geq$ 26 days/month	0.3	
Self-reported health status	rating of 'excellent' or 'very good'	0.1	
Safety	not been a victim of crime in past 12 months	0.3	Community Vitality
Family	$\geq$ 16 in family relationship score	0.2	
Community Relationship	self-reported sense of belonging at least 'very strong' and trusted at least 'some of them' in the community	0.2	
Donation (time and money)	$\geq$ 10% of household income was made and volunteered $\geq$ 3 days in the past 12 months	0.3	
...	...	...	...

lighter weights attached to highly subjective variables. A threshold or sufficiency level is applied to each variable. At the level of domains, all the 9 domains are equally weighted as they are all considered to be equally valid for happiness.

The following domains were unlisted in Table 2:

- Ecological diversity and resilience
- Good governance
- Culture diversity and resilience
- Time use
- Psychological Wellbeing

1.3 Sustainability (S)

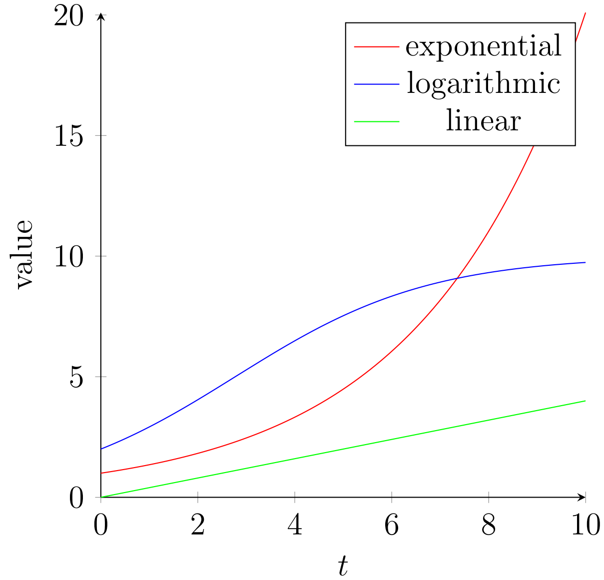
A village that maintains standard of living and quality of life may not be able to do so over time – this is what we want to capture with our *Sustainability* dimension index. Here, the *Sustainability* dimension index is an aggregate of six indicators – Δ Growth, Short and Long Term Investments, Cooperation and Dependencies, Adaptability to Modernization: Technology, Capacity for Innovation, and Natural Capital – combined using an unweighted, arithmetic mean. Further debate may result in a geometric aggregation approach to account for compounded effects.

$$S = \frac{R + I_G + D + T + C + K_N}{6} \; ; [0,1] \tag{6}$$

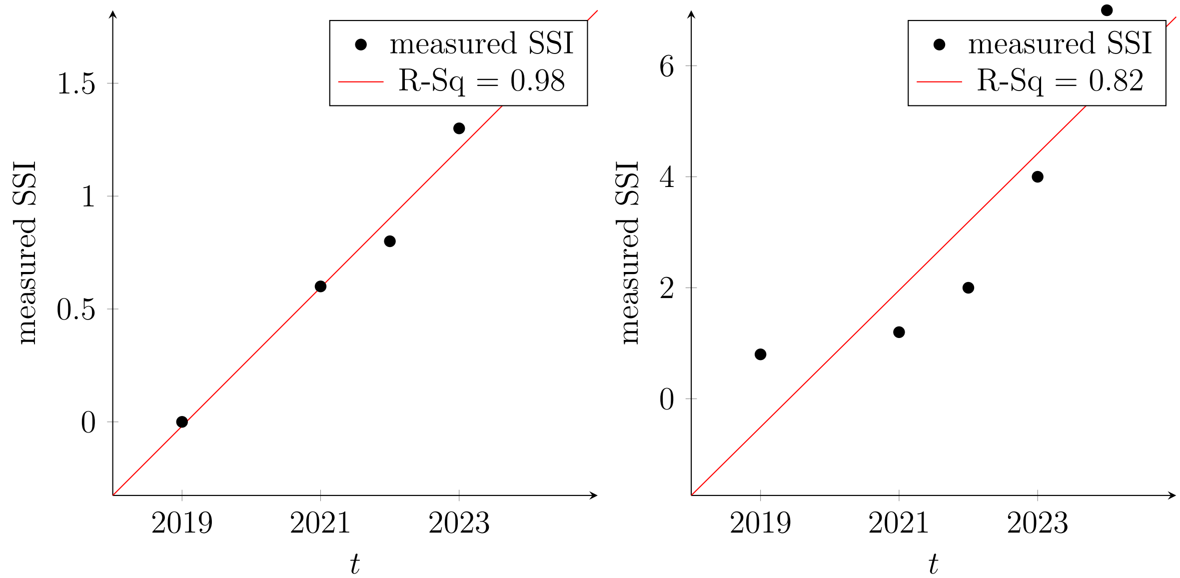
or

$$S = \sqrt[6]{R \, I_G \, D \, T \, C \, K_N} \; ; [0,1] \tag{7}$$

1.3.1 R, Δ Growth



We find plenty of examples in the real world of growth narrowly focused on adding capital. Since 1990, China has averaged a high GDP growth rate of around 9% per year, peaking at 14% in 1992. This has resulted in rapid extraction and depletion of natural resources along with pollution, health effects, and decreased standard and quality of living with industrialization. Here, we consider monitoring growth patterns and encouraging more sustainable growth as a model of development.



We achieve this by fitting SSI index values from the previous 5 to 10 years – thereby inserting memory into our index – into a linear regression, before taking an R-squared goodness of fit test, which rewards healthy growth models.

1.3.2 I_G, Short and Long Term Investments

Here, we only examine local government investments, converting into an indicator $I_G \in [0, 1]$:

$$I_G = k_{short} \frac{I_G^{short}}{I_G^{total}} + k_{long} \frac{I_G^{long}}{I_G^{total}} \tag{8}$$

where $k_{short} + k_{long} = 1$

1.3.3 D, Cooperation and Dependencies

There's an argument here that cooperation and dependencies are already accounted for by our negative weighting of imports and exports in our SoL dimension index aggregation. However, we want to explicate (1) the sensitivities of our village on the interconnected network, and (2) measure how our village's dependencies compare. Sensitivity should be a compounded feature in our final SSI index, as an important measure of resilience [5]. It's important to note here that no village can be entirely self-sufficient – at least, not easily and only after a long period of time – nor is this the ideological goal. The distinction between self-sufficiency and isolation is in its scale of dependencies, and not the altogether lack of dependencies.

Our indicator ϵ sweeps through the domains outlined by our SoL index (e.g. nutrition, water, waste management) and examines % reliance, in some cases negative as our exports exceed imports. D, as discussed later, is normalized $\in [0, 1]$.

$$\epsilon = \sum_{x \in I} \left[\gamma^{x}_{priority} \frac{\delta SoL^{x}_{X}}{SoL_{X}} \bigg/ \sum_{v \,\in\, villages} \frac{\delta SoL^{v}_{x}}{SoL^{v}_{x}} \right] \tag{9}$$

Note, we can also measure sensitivity to dependencies from the opposite approach, that is, looking at what we import (M), as being sensitive to the consumption behaviors of other villages, $v \in$ the set $villages$

$$\epsilon = \sum_{x \in I} \gamma^{x}_{priority} \left[\sum_{v \,\in\, villages} \frac{\delta SoL^{v}_{x,X}}{SoL^{v}_{x,X}} \bigg/ \frac{\delta SoL_{x}}{SoL_{x}} \right] \tag{10}$$

Here, it makes sense to normalize by a purely max-min comparative method used in the OECD Better Life Index [6], as our sensitivity ϵ is directly related to the sensitivity scores, ϵ, of other nodes in the network.

Both *(7)* and *(8)* are indicators with a negative tendency – high value implying "poor."

Normalization scheme:

$$\epsilon_{normalized} = \frac{\epsilon_{initial} - \epsilon_{\text{max across villages}}}{\epsilon_{max} - \epsilon_{min}} \tag{11}$$

1.3.4 T, Adaptability to Modernization: Technology

To ensure rural India is attuned to modern technology where new strategies can benefit related sectors, we have an indicator, $T \in [0, 1]$, which sweeps through the domains outlined by our SoL index (e.g. nutrition, water, waste management) and examines what proportion of state-of-the-art national solutions have been adopted in the village. This is again weighted by the same SoL domain priorities.

$$T = \sum_{x \in I} \gamma^x_{priority} \,\%\text{Adoption} \tag{12}$$

where $\%\text{Adoption} = \frac{\#\text{ strategy implemented}}{\text{total }\#\text{ national strategies}}$

1.3.5 C, Capacity for Innovation

Similar to T, we sweep through our SoL domains and need to consider different normalization schemes, especially those that do not limit innovation, so as to incentivize local productivity. Here, we look at what proportion of strategies are imported, which strategies are exported, and assess across degree of locality (see distance weighting discussed in **1.1 SoL**) (for imports, M) and degree of influence (for exports, X).

$$C = \sum_{x \in I} \gamma^x_{priority} \left[1 - \gamma^x_{d,M} \frac{\#\text{ strategy imported}}{\text{total }\#\text{ strategies}} - \alpha^x \frac{\#\text{ strategy exported}}{\text{total }\#\text{ strategies}} \right] \tag{13}$$

where α_x = influence coefficient.
There are a variety of approaches for choosing α_x. As a brief survey, we can find the proportion, $\frac{\#\text{ strategy exported}}{\text{total }\#\text{ strategies}}$, for all villages – presupposing mass adoption, or at least enough villages participating in SSI evaluation for statistically reliable results – and either implementing a percentile scheme or an inverted z-score scheme for non-Gaussian and Gaussian distributions. We can also consider a piecewise grading of innovation, based on adoption rates from other villages (another axis to consider is distance – *should innovation be locally retained?*).

Owing to the small size of the village and the potential nimbleness of local government in a federal system, our hope is that innovation can occur rapidly and concurrently across villages; each village motivated by its unique environmental, cultural, and social contexts, while grounded in global best practices and feedback from the network. The village becomes one node in a distributed network of creation and intelligence.

1.3.6 K_N, Natural Capital

Broadly, there exist two important ideological approaches to environmental stewardship:

1. **Preservation from an ecocentric perspective:** This is what environmental ethicist John Muir advocated for in his work at the Sierra Club in the United States. Ecocentrism emphasizes the inherent value of nature without utility to humans. If we adopt this ideology, *intactness* should be the principal indicator for K_N.

2. **Harmony and Symbiosis between nature and humans:** If we believe or rather, strive towards joint beneficence, then our indicators should reveal an active relationship between the village and nature, while also considering resilience.

Note that a good precedence for the ideology outlined in **1** is the Index of Ecological Integrity, created by the Conservation Biology Institute [9]:

> The index of ecological integrity (IEI) is a measure of relative intactness (i.e., freedom from adverse human modifications and disturbance) and resiliency to environmental change (i.e., capacity to recover from or adapt to changing environmental conditions driven by human land use and climate change). It is a composite index derived from up to 21 different landscape metrics, each measuring a different aspect of intactness (e.g., road traffic intensity, percent impervious) and/or resiliency (e.g., ecological similarity, connectedness) and applied to each 30 m cell. The index is scaled 0-1 by ecological system and geographic area . . . Scaling by ecological system means that all the cells within an ecological system are ranked against each other in order to determine the cells with the greatest relative integrity for each ecological system within the specified geographic extent.

SSI adopts **2**, as the village should *responsibly* use and take care of all resources within its boundaries. Thus, we follow guidelines by the Natural Capital Measurement Catalogue (NCMC) [3], where:

$$K_N = K_N^{accounting} + K_N^{assessment} \tag{14}$$

where $K_N^{accounting}$ takes stock of assets and flows of benefits from assets:

$$K_N^{accounting} = \text{environmental assets} \ + \ \text{ecosystem assets} \tag{15}$$

$$\begin{aligned} \text{environmental assets} &= \text{stocks} + \text{flows} \\ &= (\text{quantity} \times \text{quality}) \ + \ (\text{physical} \times \text{monetary}) \end{aligned} \tag{16}$$

$$
\begin{aligned}
\text{ecosystem assets} &= \text{stocks} + \text{flows} \\
&= (\text{extent} \times \text{condition}) + (\text{physical} \times \text{monetary})
\end{aligned} \tag{17}
$$

Note here that choosing a monetary axis for valuing flows may be tuned to include multiple axes in the future. For example, a "hero"/target variable such as carbon sequestration.
$K_N^{assessment}$ measures an entity's impacts and dependencies on K_N:

$$
K_N^{assessment} = \text{impacts} + \text{dependencies} \tag{18}
$$

Note that missing from our current K_N discussion is a normalization scheme.

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