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The index of sustainable functionality: an application for measuring sustainability

G.T. Cirella and L. Tao

Abstract**—**The index of sustainable functionality (ISF) is an adaptive, multi-criteria technique that is used to measure sustainability; it is a concept that can be transposed to many regions throughout the world. An ISF application of the Southern Regional Organisation of Councils (SouthROC) in South East Queensland (SEQ) – the fastest growing region in Australia – indicated over a 25 year period an increase of over 10% level of functionality from 58.0% to 68.3%. The ISF of SouthROC utilised methodologies that derived from an expert panel based approach. The overall results attained an intermediate level of functionality which amounted to related concerns of economic progress and lack of social awareness. Within the region, a solid basis for future testing by way of measured changes and developed trends can be established. In this regard as management tool, the ISF record offers support for regional sustainability practice and decision making alike. This research adaptively analyses sustainability – a concept that is lacking throughout much of the academic literature and any reciprocal experimentation. This lack of knowledge base has been the emphasis of where future sustainability research can grow from and prove useful in rapidly growing regions. It is the intentions of this research to help further develop the notions of index-based quantitative sustainability.

Keywords**—**environmental engineering, index of sustainable functionality, sustainability indicators, sustainable development.

I. INTRODUCTION

THE amalgamation of sustainability science into numerous levels of society is on the increase in recent years. This transition toward a sustainable level of development is mostly founded upon the complex dynamic relationships between environmental, social and economic issues [1]. One innovative quantitative sustainability concept is the use of an index-based approach [2-5]. This concept evolved from both qualitative and quantitative methodologies. From this study it is evident the ISF theory shows characteristics from the environmental sustainability index [6], the human development index [7-10], the index for sustainable economic welfare [11], the gross happiness indicator [12], the ecological footprint [13] and the genuine progress indicator (GPI) [14]. The ISF utilises an objective, quantitative multi-criteria method to examine and measure sustainability. From this viewpoint, it is hopeful this type of research will promote ideas and recognition for better development in and around rural and urban settings.

This study examines the SouthROC which is located in SEQ, Australia; the SouthROC is one of four local government regional collaboration groups that existed in SEQ until the 15 March 2008 council amalgamation process implemented by the State of Queensland Labour Government [15]. The SouthROC has Queensland memberships from Beaudesert Shire Council (BSC), Gold Coast City Council (GCCC), Logan City Council (LCC), and Redland Shire Council (RSC) (Fig. 1) [16]. This study is labelled the ISF of SouthROC; it is one of Australia's fastest growing regions and is experiencing accelerated change from a booming population and strong economy. This scenario discloses an excellent backdrop for the use of an ISF application.

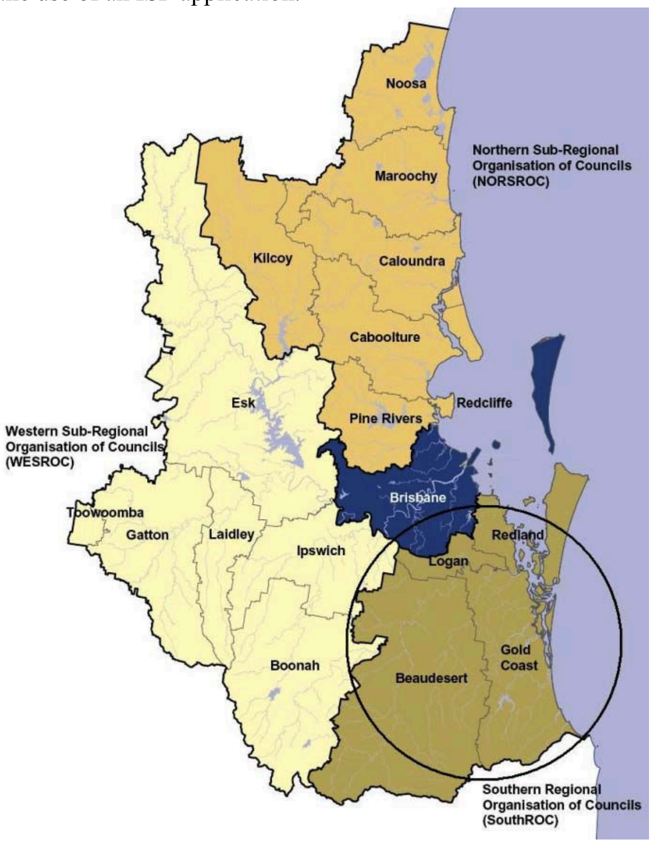

Fig.1. Map of SEQ with the SouthROC area circled.

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II. Methods

The methods used for the ISF of SouthROC measure sustainability using the premise of an engineering scope and matrix-based approach. It is quantitative in that it institutes an approach of measuring sustainability via adaptive means which incorporates complex interactions recorded over time to establish traceable records of sustainability trends. The process of contributing or being able to adapt to these trends is fundamental to the ability to act, or begin to act, sustainability-friendly [17]. The methodology of the ISF of SouthROC is made up of two parts: structure and mathematical formulation. The structure is broken down into five steps that identify and define variables while the mathematical formulation implies the application of the ISF formulae.

A. Structure Methodology

First, to construct the definition of the ISF the identification of various terms and variables must be allocated. The region in which the study is to take place is labelled the domain (D); if there are sub-domains (D_i) they are a spatial resolution within the domain. This project recognises the domain as SEQ (D) which has four sub-domains: the Northern Sub-Regional Organisation of Councils (NORSROC) (D_1), the Western Sub-Regional Organisation of Councils (WESROC) (D_2), SouthROC (D_3) and Brisbane City Council (Brisbane) (D_4). The extent of this paper will only cover the sub-domain of the SouthROC (D_3) (Table 1). The formation of the SouthROC is subdivided into four councils: BSC, GCCC, LSC and RSC.

TABLE I
The domain, sub-domains and systems of the ISF of SEQ.

Domain	D SEQ			
Sub-domains (D_i)	D_1 NORSROC	D_2 WESROC	D_3 SouthROC	D_4 Brisbane
Systems (S_{ij})	S_{11} NORSROC - Natural	S_{21} WESROC - Natural	S_{31} SouthROC - Natural	S_{41} Brisbane - Natural
	S_{12} NORSROC- - Social	S_{22} WESROC - Social	S_{32} SouthROC - Social	S_{42} Brisbane - Social
	S_{13} NORSROC - Individual	S_{23} WESROC - Individual	S_{33} SouthROC - Individual	S_{43} Brisbane - Individual
	S_{14} NORSROC - Economic	S_{24} WESROC - Economic	S_{34} SouthROC - Economic	S_{44} Brisbane - Economic

Second, it is necessary to identify the matrix-based approach by labelling systems (S_{ij}) and perspectives ($P^k{}_{ij}$) on opposite sides of a matrix. The systems of the ISF of SouthROC are mechanisms of the domain which jointly correspond to all aspects of its sustainability. There are four systems for the SouthROC labelled natural (S_{31}), social (S_{32}), individual (S_{33}) and economic (S_{34}). The numerical values for each of the systems identifies with the project scope (Table 1 illustrates this by labelling the variables of each system). The perspectives are intra or inter-domain related views [18, 19] that are located opposite to their system in a cross-reference pattern [17]. The perspectives are commonly influenced by the domain [4] and skeleton the viewpoint of the function selected for measurement. This study uses three perspectives – environmental, social and economic – based on a triple bottom line (TBL) approach. By applying this to the ISF framework, assessment approaches can be positioned relative to one another, enabling comparison on the basis of substance rather than semantics [20].

Third, the structure of the methodology must identify that systems have the aptitude to safeguard certain functions ($F^k{}_{ijl}$), that is, functions are the activities that a specific system should be carrying out for a particular perspective [4, 17]. Using a system-perspective approach functions utilise specific indicators that are tested against its relating function. This defines an indicator as a tool in which data can be analysed and simplified for changes in sustainability. Thus, indicators are to be clearly associated with the function they are testing against, be scientifically valid, and be available over time and for comparison to thresholds [17, 19]. For the ISF of SouthROC the functions totalled 24 while the indicators totalled 60. Both functions and indicators are founded from sources such as government reports, interviews, technical papers and literature alike. A list of functions and indicators used can be found in Table 2. The ISF of SouthROC is quantified into 5 year blocks from 1980 to 2005 hence the time period of the study examines a 25 year span.

Fourth, the next step is data normalisation; this step entails the process of establishing a universal standard of measurement between the different scales and units of each indicator. Normalised indicators ($I^k{}_{ijlm}$) are defined with upper and lower functional bounds which are assigned to a value between zero and one. The definition of the upper and lower assigned values equals zero when it is at its worst state or situation and one when it is at its best state or situation. Thus, when the system operates at full dysfunctionality it is regarded as being at the lowermost level or equal to zero, whereas when the system is at one it is calculated to be at the uppermost level of functionality hence is fully functional [17].

Fifth, the last step of the methodological structure examines the weightings ($W^k{}_{ijlm}$) and the aggregation of the data. This is the preparation of data for the formulation of the ISF results. The weightings of the data are determined by the use of an expert panel. In this case, the expert panel comprised of nine persons from various professional backgrounds. The expert panel ranks each function-to-perspective and indicator-to-function relationship. The aggregate of the weightings from the expert panel is used to limit the bias and/or subjectivity of the functions and indicators. Aggregation is done by using the percentile weightings on the normalised indicator datasets and then using those values on the weighted normalised indicator

TABLE II
LIST OF FUNCTIONS AND INDICATORS USED FOR THE ISF OF SOUTHROC.

S	***P***	***F***	***I***		***I_i (sub-indicator, if used)***				
Natural	Environmental	*1*		***To maintain imperative ecosystem processes***					
			1	Water quality distributed to the general population	pH balance	Dissolved O_2	Phosphorus	Nitrogen	*E. coli*
		2		***To maintain related linkages between diversity of plant and animal species in an environment***					
			2	*Percentage completion of the State nature conservation strategy for Queensland*				Habitat destruction	
		3		***To uphold climate change initiatives***					
			3	Renewable energy consumption and/or usage		Wind	Solar	Biomass	Wave/Tidal
			4	Carpooling within the region					
			5	Percentage of public transport used					
			6	Percentage of commercial businesses that include climate change initiatives as part of their corporate plan					
			7	Percentage of local government initiatives implemented that promote Queensland's State Government initiatives on climate change					
	Social	*4*		***To provide aesthetic and recreational use of nature for the community***					
			8	Area of protected land area as a percentage of total land area					
		5		***An environment beneficial to human health***					
			9	Normalised air quality levels		Ozone	NO_2	Part. matter	Air quality
	Economic	*6*		***The provision of natural aesthetics for economic benefit***					
			10	Price of a property with waterfront or beachfront view as a percentage of the price of a similar property without a view					
			11	Percentage change in price of a property with a waterfront or beachfront view, compared to percentage change in price of a similar property w/o view					
			12	Percentage change in price of a property next to a green space compared to percentage change in price of a similar property further from green space					
		7		***To provide renewable and non-renewable resources***					
			13	Renewable resource - annual water consumption trends					
			14	Non-renewable resource - total fossil fuels value against gross regional product				Coal Production	
Social	Environmental	*8*		***To conserve the natural environment responsibly through government policy, legislation and services and through public awareness and involvement in environmentally-friendly initiatives***					
			15	Percentage of solid waste recycled					
			16	Percentage of regional expenditure allocated to 'green spaces'					
			17	Percentage of regional expenditure allocated to sustainable development					
			18	Percentage of wastewater reused					
	Social	*9*		***To provide all individuals in society with equitable opportunities and outcomes – via the provision of basic services***					
			19	Weekly income by gender					
			20	Number of deaths per year due to heart disease					
			21	Percentage of annual government expenditure allocated to health					
			22	The number of violent and property crimes per 1000 residents					
			23	Percentage annual government expenditure allocated to law, order and public safety					
		10		***To promote and encourage a diverse, interrelated and participative society***					
			24	Equity of political representation					
			25	Proportion of indigenous residents, residents born overseas and Australian born residents from outside the region compared with the whole region					
			26	Percentage of residents with a high school education					
			27	Percentage of annual government expenditure allocated to education and welfare					
			28	Percentage government expenditure allocated to recreation and culture					
	Economic	*11*		***To support business and industry through appropriate, innovative and effective implementation of policy and management strategies by the local government***					
			29	Percentage of annual council expenditure allocated to economic development					
			30	Average business satisfaction rating					
		12		***To provide a stable social society***					
			31	The number of crimes reported per capita					
			32	Funding to local tertiary universities and TAFE within the region					
			33	The number of people who own or who have purchased (via mortgage) a home in which they are residing					
Individual	Environmental	*13*		***To minimise the consumption of finite resources***					
			34	The number of cars per individual					
			35	Residential energy consumption per capita					
		14		***To minimise waste output***					
			36	Household waste to landfill					
			37	Proportion of households that participate in kerbside recycling					
	Social	*15*		***To contribute to the continued safeguarding of population maintenance***					
			38	Population distribution via population growth					
			39	Population distribution via total fertility rate					
		16		***To contribute to the continued function of the social system through participation***					
			40	Fraction of total number of participants that are held within the workforce					
		17		***To contribute to the continued function of the social system through compliance***					
			41	The cumulative impact of criminal offences, weighted by the severity of the offences					
			42	Fraction of police force of total population versus the cumulative crime rate					
	Economic	*18*		***To provide human capital in the form of knowledge and labour for production***					
			43	The proportion of working aged population with only a school qualification					
			44	Participation rate of population in secondary and tertiary education					
		19		***To consume available goods and services***					
			45	Total of goods and services as a proportion of average weekly household disposable income					
			46	Remainder of income after servicing of debt and investments as a proportion of average household disposable income					
Economic	Environmental	*20*		***To minimise adverse impacts of industry on the environment***					
			47	Total energy use by industry per gross regional product					
			48	Total energy use by industry that is from renewable sources					
			49	Industrial solid waste to landfill per gross regional product					
			50	Fraction of total solid waste by industry that is recycled					
	Social	*21*		***To ensure affordability and provision of basic needs***					
			51	Fraction of working population whose income is over the minimum wage					
			52	Percentage change in cost of housing versus percentage change in gross disposable income					
		22		***To create diversity and opportunity***					
			53	Gender equality as a deviation from 50% across all industries					
			54	Occupied job types as fraction of total number of possible job types in the economic system					
	Economic	*23*		***To provide accurate measures for all forms of capital which are traded in the local economic system***					
			55	Measuring stability in the economic system					
			56	Measuring economic growth					
			57	Measuring equity accessibility of markets					
		24		***To contribute to stability and progression towards growth in the region***					
			58	Growth rate in region					
			59	The stochastic diversity of the regional industry diversity compared to Australia's industry diversity					
			60	Growth rate of people employed in the region's industries					

datasets. This results in a weighted sum of indicators which allows for the calculation of the normalisation of functions. Once functions have been normalised the structure of the SouthROC is finalised and the results can be used to compute the ISF record. This step is further detailed in the next section, the computation of the methodology, by explaining the weightings formulation process.

A. Mathematical Formulation

The formation of the sub-domain for the ISF of SouthROC is divided into four council regions: BSC, GCCC, LSC and RSC. Four independent ISF values are created for each council, and divided by four, that is, the total number of councils measured, to create the ISF of SouthROC. This method is constructed on the basis that each council is equally represented regardless of geographical size, demographic or land use. This self-determination approach also backs the structure of the study by focusing on regionalism, an important aspect of sustainability-thinking. The computation of the ISF of SouthROC uses formulae that originate from Imberger et al.'s research [4] but have been modified and expanded in many regards. The significance of these changes to the computational methodology expands on the notions of further breaking down the weightings process to the function- and indicator-level. This is important because it is the first time the ISF has been examined at this scale. The subsequent formulae use the defined variables from Table 3.

TABLE III
VARIABLES USED IN THE ISF MODEL.

Symbol		Definition
i	=	sub-domain
j	=	system
k	=	perspective
l	=	function
m	=	index or weighting
r	=	rank level
n	=	total number
Ω	=	averaged function
ω	=	averaged indicator
B	=	before value
A	=	after value
Δ	=	internal years

The formulation of the weighted perspective (W_P) (1) calculates the functions-to-perspectives weighted relationship from the expert panel. This is used to define how much weight is given to each function representative of its perspective.

$$W_P = \frac{\dfrac{\sum_{r=5}^{1} \Omega_r r}{\sum_r}}{\max(r)} \qquad (1)$$

The formulation of the weighted functions (W_F) (2) is similar to (1) in that it calculates the indicators-to-functions weighted relationship. This formula defines the weight of each indicator representative of its function.

$$W_F = \frac{\dfrac{\sum_{r=5}^{1} \omega_r r}{\sum_r}}{\max(r)} \qquad (2)$$

The weightings of certain indicators-to-functions relationships need to be approximated when calculating the weighted sum of indicators of mixed datasets; that is, datasets that are structured using five year interval and before and after data. Indicators that are represented with before and after data are formulated using an indicator linear interpolation ($I_F^{Average}$) (3). This formula is used strictly to combine these two types of data to represent it for the time period allotted; for this study the five year blocks from 1980 to 2005 represent Δ which equals five interval blocks. Equation (3) is executed on the third and seventh function and produces a dataset for the calculation of the normalisation of its relating function.

$$I_{F^{Average}} = |A-B| \frac{n \times \Delta}{(A-B,(n=1\sim 4)} \qquad (3)$$

In addition to the weightings being ranked representatively, the weighted stack of the perspectives via its relating functions and functions via its relating indicators needs to be done. Weighted stack must equal 100 percent and is calculated by rounding to one decimal place. The weighted stack of perspectives (W_P^{Stack}) in (4) ranks the number of functions per perspective.

$$W_{P^{Stack}} = Round\left(\frac{W_N}{\sum_{r=n}^{1}} 100, 1 \right) \qquad (4)$$

Similar to (4), the weighted stack of functions (W_F^{Stack}) defined by (5) ranks the number of indicators per function.

$$W_{F^{Stack}} = Round\left(\frac{W_F}{\sum_{r=n}^{1}} 100, 1 \right) \qquad (5)$$

Before the normalisation of the data, the computation process must also meet the following requirements of the net normalised indicator value ($I(\lambda^k_{ijlm})$) as defined by (6), placing all values equal to and/or between zero and one. Noting that any value below zero will be equal zero and any value above one will be equal one.

$$I(\lambda^k_{ijlm}) = \begin{cases} 0 & \text{for} \quad \lambda^k_{ijlm} < 0 \\ \lambda^k_{ijlm} & \text{for} \quad 0 \le \lambda^k_{ijlm} \le 1 \\ 1 & \text{for} \quad \lambda^k_{ijlm} > 1 \end{cases} \qquad (6)$$

The summation of each product of the indicators ($I(\lambda^{k}_{ijlm})$) and weightings gives a resulting value by the use of the ISF (7). The sub-domain value of i = 3 represents the third sub-domain of the larger project of the ISF of SEQ. The following equation is used on each of the four councils considered – BSC, GCCC, LSC and RSC – each one giving a resulting ISF value. These values are added together and divided by four to create the ISF values of the SouthROC.

$$\mathrm{ISF} = \sum_{i=3}^{F} \sum_{j=1}^{F_i} \sum_{k=1}^{F_{ij}} \sum_{l=1}^{F_{ij}^{k}} W_{P^{Stack}} W_{F^{Stack}} I(\lambda^{k}{}_{ijlm}) \qquad (7)$$

In addition, the methodology points out that the advantage of separating the function from the normalised indicator reflects that the weightings may change due to priorities people and/or communities often associate with a defined set of functions. Whilst with normalised indicators, measurement of the absolute functionality of the system is more domain-related [4]. Specifically, the ISF of SouthROC integrates existing concepts of the TBL and the concept of capital theory. The perspectives – environmental, social and economic – are solely based on the TBL approach, while the concept of capital theory analyses linkages among the theories of production, growth, value and distribution. It should also be noted that the sum of individual perspectives by definition are equal to social ones therefore the individual is not a perspective [4, 17]. This methodology explains some fundamental development in the calculations of using the ISF approach in terms of quantitative sustainability.

III. Results

The findings from this study are divided into four councils; the ISF results for each council as well as for the whole of the SouthROC are presented from the years 1980 to 2005 in Table 4. Over the 25 year period, the results can be examined in detail by looking at each of the four councils' general state of functionality. The BSC increased 9.7% from 58.1% to 67.8% functionality. Details of the BSC indicate a strong growth in workforce and council objectives that focus on tackling some of its resource shortages. The GCCC increased just over 8% from 59.6% to 67.7% functionality. Its growth is extremely rapid and it scored well in many economic and environmentally related aspects mostly relating to a number of council projects and programs recently introduced. The Gold Coast is a rapidly booming region and faces many difficult decisions relating to its ever increasing demographics. Its significantly larger population makes sustainability obviously more challenging as its infrastructure and development will be under higher pressure due to expanding needs to accommodate more people. The LSC increased nearly 10% from 58.8% to 68.6% functionality. This council also has introduced numerous programs, including workforce related initiatives that show positive trends toward social and economic sustainability. It is a council that relates closely to Brisbane due to its close proximity to the large metropolitan city. The RSC increased the most at 13.7% from 55.5% to 69.2% functionality. The RSC has boosted its environmental awareness while still maintaining a growing infrastructure and population influx. It too is steadily on a positive pathway toward sustainable-living due to increased social awareness results and economic success.

TABLE IV
THE ISF RESULTS FOR THE SOUTHROC AREA.

Year	Beaudesert (BSC)	Gold Coast (GCCC)	Logan (LSC)	Redland (RSC)	SouthROC
Before					
1980	0.581	0.596	0.588	0.555	0.580
1985	0.582	0.608	0.597	0.606	0.598
1990	0.599	0.612	0.594	0.628	0.608
1995	0.613	0.605	0.625	0.634	0.619
2000	0.635	0.616	0.650	0.655	0.639
2005	0.678	0.677	0.686	0.692	0.683
After					

The findings from the four councils' results combine to construct the ISF of SouthROC. The results show an increase of 10.3% from 58% to 68.3% functionality. As a whole the SouthROC area scored an intermediate level of functionality in 2005. Some initial concerns are overdevelopment and some lack of social awareness but the trend, for the most part, is moving in a positive direction of functionality in sustainability terms.

IV. Discussion

The SouthROC can further be analysed by comparing the ISF values with the GPI [14], gross regional product (GRP), and the population growth rate (Fig. 2) [21]. From 1980 to 1990 all three indices project similar levels of linear stability. However, over the remaining 15 years from 1990 to 2005 the findings are significantly different. The GPI shows a minor increasing trend. The GRP increases 19%, indicating a huge augmentation in economic expenditure. The ISF has a linear trend that is similar to the GPI but is calculated and represents a more quantitative measure of the consequences of expenditure rather than the actually expenditure itself [17, 22].

These results suggest that when comparing the ISF, GPI and GRP the inefficiencies of using an economic-based index, like the GRP for measuring the wellbeing or sustainability of a region, falls short by over exaggerated only economic values. For the entire measured period the population growth rate steadily increased at a minor exponential rate meaning an increase of energy, resources, and land use demands region-wide. The contribution of the ISF of SouthROC as an appraisal for the region is at the forefront of index-based sustainability and can inform local governments and/or communities of the current trends of sustainability-friendly steps. The ISF trend can be used to track and reference future develops in the region [17, 23]. The development of this research suggests that as councils' functionality increase their levels of sustainability within their communities will become more aware of what entails positive sustainability trends and what does not.

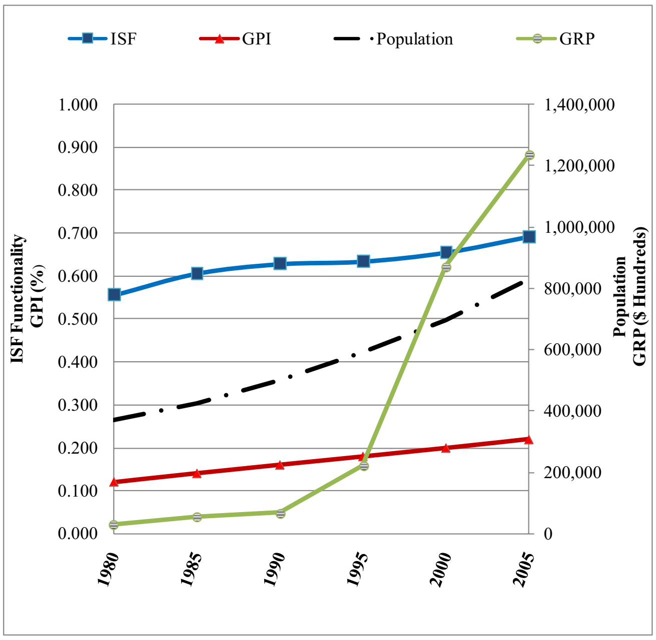

Fig. 2. SouthROC: Index of Sustainable Functionality (ISF), Genuine Progress Indicator (GPI), Population and Gross Regional Product (GRP).

Since sustainable-thinking is firstly education-based awareness it is communities at the grassroots level that need to be informed of results and relating sustainability progressiveness if bonding practice of an ISF is to be used affectively. In this regards the large amount of qualitative research that examines sustainability methods compliments quantitative thinking. Together with education and an open arena of information, tackling the issue of sustainability with both qualitative and quantitative approaches, offers a better collateral understanding for the implementation of a sustainable management tool [24, 25]. In this sense, the use of the ISF is not limited to only regionalism, as utilised in this study, it can be tailored to other practices including demographics, business and institutional structures.

V. Concluding Remarks

The use of quantitative sustainability methods as a means of developing better societies that are more sustainable and that limit the development of unsustainable actions is the premise behind the ISF design. As a management tool it can assist and/or support decision-making and resource allocation related applications. The ISF of SouthROC is part of a larger study that is being undertaken on the entire SEQ region. The findings from this research will be added to the larger study where the regional sustainability of SEQ as a whole will be determined. Furthermore, the detailed results of the ISF of SouthROC provided valuable information for the local governments, ensuring a positive move towards fostering sustainable development trends.

The continual innovation of quantitative sustainability related research is at the forefront of a novel way of thinking about what, how, why, where and with whom things and actions are done on a societal-level. Globally, it is hopeful such a management tool will assist in improving collaborative means between relating societal linkages and living within a more sustainable global ambience. As humans continue to stretch global resources to their limits and thresholds – innovative designs, approaches and techniques to better understand our desires and needs must become clearer. From this reasoning, it is clear that certain urgency is needed when dealing with such a matter as unsustainable decisions which require extensive backlashes that often are irreversible and/or very costly to restore. Sustainable-thinking remains at the forefront of this subject matter and in the span of this research is it hopeful the value of a broader scope of understanding will assist in better helping our societal development.

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