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Potential Trade-Offs between the Sustainable Development Goals in Coastal Bangladesh

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Abstract: The Sustainable Development Goals (SDGs) are offered as a comprehensive strategy to guide and encourage sustainable development at multiple scales both nationally and internationally. Furthermore, through the development of indicators associated with each goal and sub-goal, the SDGs support the notion of monitoring, evaluation and adaptive management, underpinned by the aspirations of social justice, equity and transparency. As such, the ethical intention of the SDGs is well founded. However, possible conflicts and trade-offs between individual SDGs have received little attention. For example, SDGs relating to poverty (SDG 1), inequality (SDG 10), food security (SDG2), economic development (SDG 8) and life in water and on land (SDGs 14 and 15), are potentially competing in many circumstances. In a social–ecological context, policy support and formulation are increasingly adopting systems approaches, which analyse the complex interactions of system elements. Adopting such an approach in this work, the above SDGs are analysed for coastal Bangladesh. This demonstrates multiple potential trade-offs between the SDGs, including agricultural farming approaches in the light of poverty reduction, and between economic growth and environmental integrity as well as equity. To develop coherent and policy relevant socio-ecological strategies, appropriate decision frameworks need to be co-developed across the range of stakeholders and decision-makers. Integrated models have great potential to support such a process.

Keywords: sustainable development goals; integrated assessment; model; systems approaches; trade-off; environment; sustainability; delta; coastal; Bangladesh; scenario; poverty; equity; economics

1. Introduction

The 17 Sustainable Development Goals (SDGs) express aspirations for human development that require the realisation of a universal, but diverse set of ethical principles, such as inclusion, justice, equality, dignity, wellbeing, global solidarity, sharing, sustainability and public participation. The SDGs are offered as a comprehensive set of goals to encourage sustainable development at multiple scales both nationally and internationally. They extend from the more familiar reductions in poverty to the more recent considerations of sustainable cities. The SDGs are divided into 169 targets, thereby representing an approach to benchmarking, monitoring and evaluating the progressive development of all nations following on from the relative success of the MDGs in line with principles of transparency and accountability. The SDGs are hence deeply ethical and based on the recognition of moral obligations and the imperative to address not only poverty but welfare and equity [1].

The ethical intent of the SDGs would seem to be well founded, with their formulation based on an extensive participatory process, and the objective is widely recognised as normative. The resulting SDGs are intentionally broad and inclusive, but they include elements of different ethics, and are vague in how these ideals should be realised and translated into pathways for development [2,3]. Moreover, the SDGs and their targets are associated with each other in multiple ways, and these relationships need to be elucidated and explored [4].

Therefore, when translated into actions, decision-makers are likely to encounter a series of value conflicts in prioritisation, related to whose stakes count (e.g., current or future generations), which criteria should be used for the goals (e.g., income or multidimensional wellbeing), and which weight should be given to these decision components. These value conflicts are embedded in different ethical stances, worldviews and different ideas of justice (e.g., the social contract that arranges the distribution of welfare, rights and freedoms [5,6].

The lack of integration of the SDGs and consideration of incompatibility and feedbacks, especially those on economic development and ecological sustainability, have been recognised as a critical limitation, yet key to their application and realisation [7–9]. Emerging literature identifies a series of potential policy relevant conflicts when aiming to achieve multiple SDGs simultaneously [1,10,11]. This raises the issue of trade-offs between different SDGs that has received little attention to date, and yet needs to be addressed if the SDG process is to deliver its full potential. Indeed, it has been argued that the SDGs fall short of a comprehensive solution in such fields as inclusive or sustainable development, which considers the integration of the complex dynamics of social, ecological, and economic development [12]. This doubt is echoed in the call for more stringent assurances that sustainability will not be secondary to economic growth, which in many cases would require a reduction in the overall resource use of economies as a target for the SDG implementation or a focus on human wellbeing as the key measure of the success of economic development [13]. Hence, the recognition of potential incompatibilities between SDGs raises critical ethical, but currently open, questions about their application, how they interact with decision-making processes, priorities and motivations for sustainable development, inequalities and the winners and losers emerging in the management of social–ecological systems.

In a social–ecological context, policy support and formulation are increasingly adopting systems approaches which analyse the interactions of system elements and allow for complex behaviour [14,15]. These generate insights into both the complex interactions of the different SDG domains and, critically, identify conflicts of interest between them, raising the need for trade-off decisions. This paper offers insights from an integrated assessment analysis of the coastal zone of southwest Bangladesh (Figure 1). The ΔDIEM (Delta Dynamic Integrated Emulator Model) framework and model comprises a comprehensive dataset and an integrated assessment model [16,17]. The model harmonises biophysical inputs across a range of scales and examines their implications for rural livelihoods and poverty. It does this representing a wide range of large-scale structural and non-structural interventions and, as such, is useful in the support of large-scale planning. This model allows examination of the complex social–ecological interactions of rural agricultural livelihoods, ecosystem services and poverty both today and over the next few decades using multiple indicators, which can be associated with multiple SDGs. Within the model outputs and associated work, ethical issues become apparent as the fulfilment of one disadvantaged group of people may interfere with the fulfilment of another group. These results challenge decision makers to consider what assumptions and criteria we utilise to evaluate these conflicts and make trade-offs.

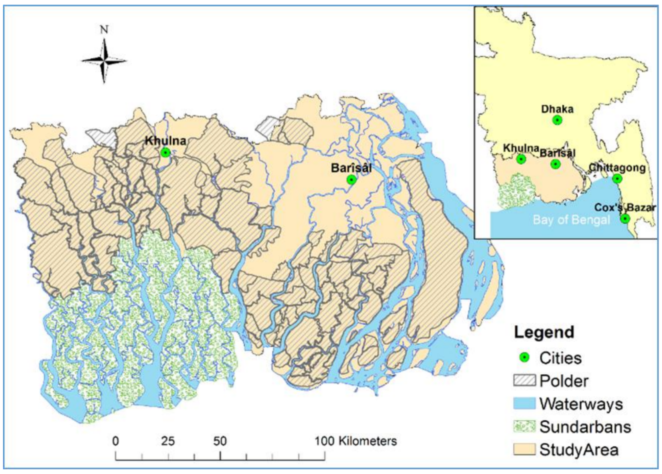

Figure 1. Study site considered by the ΔDIEM model in south-west coastal.

The Ganges-Brahmaputra-Meghna (GBM) delta covers most of Bangladesh and elements of West Bengal in India. This is a densely populated area with some 100 million people across both India and Bangladesh [18]. However, despite being a region of high agricultural productivity, there remains substantial and widespread poverty and inequity [19]. With an estimated, heavily urbanizing, population of some 200 million by 2050 and rapidly increasing GDP [20], the pressures on agricultural production are unrelenting. Rural livelihoods are inextricably linked with the natural ecosystems, with demands on agriculture, fisheries and access to non-timber forest products of the Sundarbans being dominant [21]. However, the people of this delta and the livelihood upon which they depend are endangered by long-term environmental change, including enforced land use change (e.g., conversion of agricultural land to shrimp farming), sea-level rise, storm surge impacts, and salinization of the delta front. [22–24]. A process exacerbated by dam and/or barrage construction in India and water management within both Bangladesh and India reducing freshwater flow into the delta and increases seawater intrusion [25].

Clearly, the issues that are impacting the coastal zone of Bangladesh, as with all large socio-ecological systems, are both diverse and complex. It is for this reason that the SGDs are extensive and comprehensive in their approach to capturing the biophysical and sociological context for development, but it is also for this reason that an integrated approach is required.

This paper outlines a series of case studies in such a way as to show how such integrated approaches can support not only the integration of the SDGs but reveal their trade-offs as well. The work also elucidates gaps in knowledge that need to be addressed to explore further these relationships. The work presented here demonstrates examples from a complex Integrated Assessment Model (IAM) that, when considered in the context of the SDGs, offers insight into trade-offs between policy objectives and the first-order trade-offs within the SDGs.

The SDGs identified in this paper focus on the recurrent issues surrounding economic growth, poverty, environmental degradation, inequality and food production. These are identified in Table 1.

Table 1. Key SDG considered for trade-offs within the modelled approach (UNDP, 2015).

SDG 1.	No poverty	Eradicating poverty in all its forms by 2030.
SDG 2.	No hunger	End all forms of hunger and malnutrition by 2030.
SDG 8.	Decent work and economic growth	The SDGs promote sustained economic growth and higher levels of productivity.
SDG 10.	Reduced inequalities	Reduce inequality within and among countries.
SDG 14.	Life below water	To sustainably manage and protect marine and coastal ecosystems.
SDG 15.	Life on land	To conserve and restore the use of terrestrial ecosystems.

The SDGs relating to food security (SDG 2), terrestrial and marine resource management (SDG 14 and 15), economic development (SDG 8) and reduction in poverty and inequity (SDG 1 and 10) can, and do, directly compete with each other through the sustainability of food production processes and the demands of urbanisation [7,12,13]. Such insight is extremely relevant for policy development, as it calls for processes of trade-off decisions, compromise and planning of strategic development pathways. The recognition of this raises critical ethical questions about potential pathways and compromises to achieve a balance between the SDGs, and demands transparent scrutiny of priorities and motivations for sustainable development, as well as the identification of winners and losers (of wellbeing, rights, freedoms and autonomy) emerging in the management of social–ecological systems.

Integrated or systems model approaches have been used in the literature to establish conceptual and data frameworks which allow for the identification, examination and dynamic testing of specific socio-ecological trade-offs [16] that are of direct relevance to the SDGs. Indeed, the SDGs have been used to highlight trade-offs between efforts to intensify agriculture (driving economic growth and food security), local water security, including during extreme weather events, and the livelihood security of poorer communities dependent on ecosystem services [26,27]. Such studies can, for example, explore contrasting development pathways under climate change and identify solutions to emerging problems that threaten development goals [28]. While such models are difficult to validate comprehensively, due to the scale and complexity of the systems they replicate, they provide useful insights addressing key policy questions, by examining the diverse, and sometimes unexpected, impacts across the broader thematic components of complex socio-ecological systems. When used in a participatory manner, they can promote dialogue and new thinking about difficult and sometimes almost intractable problems [29].

The examples used in this paper are drawn from the ESPA Deltas project [16], which aims to provide policy makers with the knowledge and tools to enable them to evaluate the effects of their decisions on people's livelihoods in rural coastal Bangladesh (Figure 1). The study focuses on the southwest coastal zone of Bangladesh, which provides a home for about 14 million people. The area comprises one of the world's largest coastal lowlands (with elevations from 1 m to 3 m above sea level) which is susceptible to both fluvial and coastal flooding. Much of the coastal zone is polderised (i.e., reclaimed low-lying land enclosed by embankments). The 105 polders of SW coastal Bangladesh allow year-round agriculture and provide protection against monsoonal, spring tide and to a lesser extent cyclone flooding. Between 1909 and 2009, the coastal zone was affected by cyclones with a classification of "Tropical Storm" or above on the Saffir–Simpson scale at least once every two years and extreme environmental events are a major factor inhibiting development [16,17,29].

2. Materials and Methods

The delta has important ecosystem services, especially agriculture which provides livelihoods for the majority of the coastal population. This area is highly socio-ecologically dynamic due to the constant interaction of bio-physical slow and fast processes (e.g., salinization and fluvial flooding) and anthropogenic pressures (e.g., high population density, intensive land use, and expanding aquaculture) [17]. To understand this complex system, a multi-disciplinary and multi-national team of policy analysts, social and natural scientists, and engineers developed an analytical framework and an Integrated Assessment Model (IAM) to evaluate changing ecosystem services, livelihoods and poverty across coastal Bangladesh [16,17]. This included a strongly participatory approach with policy relevant stakeholders. The engagement with some 50 stakeholder institutions and a process of stakeholder development of scenarios was outlined by Nicholls et al. (2016) [16]. The multiple drivers considered include subsidence and sea-level rise, land degradation and population pressure in delta regions amongst many others (Table 2).

Table 2. Socio-economic and biophysical variables utilised in the development of the Business as Usual (BAU), More Sustainable (MS) and Less Sustainable (LS). These variables were identified and weighted by stakeholders and given an indication of improvement or decline under differing scenarios in 2050.

Natural Resource Management	Food Security	Health/Livelihood Poverty	Governance
Salinity Impacts	Availability/Access	Migration	Conflict and Power Structure
Hydrology/Sediment	Water Security	Infrastructure	Financial Capital
Land Use	Nutrition	Water and Sanitation	Civil Society
Coastal Defence	Agricultural Tec.	Livelihood Diversification	Local Management

ΔDIEM [16,17,30] is an Integrated Assessment Model (IAM) based approach coupling biophysical, socioeconomic and governance processes to consider a range of plausible futures. The spatial resolution of ΔDIEM is at the lowest administrative tier (Union Parishad, ~26 km^2 in size and some 20,000 population). The temporal resolution is daily for the bio-physical and monthly for the socio-economic calculations. The bio-physical environment is based on statistical emulators (trained on high fidelity models; coastal hydrology, Delft-3D; river salinity, FVCOM; and groundwater height and salinity, MODFLOW-SEAWAT) and also on process-based calculations (soil salinity and agriculture—own development) [31] ΔDIEM simulates the livelihood potential, well-being and health of 36 household types. The household-level calculations are developed based on the ESPA Deltas' qualitative and seasonal quantitative surveys of 1586 households [32] and are similar to an agent-based model [33]. All calculations are tightly coupled in Matlab [34]. Model testing and validation had been conducted extensively and reported in the above publications. In brief, the hydrological emulators reproduce well the high fidelity model results with larger errors at the lower values and smaller errors at the higher values (mean RMSE, for example, for inundation depth: 0.012–0.13 m; river salinity: 1.36 ppt; and river elevation: 0.35 m). The crop simulations fit similarly well the observations at both district and sub-district levels. The RMSE for farmer's yield was 2.3–11.9% for most crops in 2010. Wheat and potato were less well simulated (RMSE: 22–70%), but these are minor crops in coastal Bangladesh. The household wellbeing simulations also compared well with total expenditure, calorie intake, protein intake, GINI coefficient and 1.90 USD/capita/day headcount observations [35].

Given a particular development trajectory, including interventions (e.g., increasing the embankment heights or subsidizing certain agriculture products), ΔDIEM can assess the resulting implications of change over time on the ES-based livelihoods and well-being of the people in coastal Bangladesh, from a regional scale (Figure 1) down to the lowest administrative tier (i.e., Union). Simulations focus on the next 30 years (to 2050) over which they are considered socio-economically valid, but can extend to 2100 for biophysical and exploratory purposes. The model can consider a wide range of environmental changes, natural hazards and climate change, and policy interventions, in varying permutations, which are of relevance to interpreting several SDGs. Figure 2 identifies the linkages between the structure of ΔDIEM and relevant SDGs. The Government of Bangladesh have identified that the meeting of their national development goals and the SDGs will require a major programme of investment over the course of the 21st century (Bangladesh Delta Plan 2100, BDP2100 [36]). Without action, it is estimated that there would be a net departure of 18 million people from the coastal and riverine vulnerability hotspots in Bangladesh, placing considerable pressure particularly on their ambition to eradicate extreme poverty by 2030 according to the BDP2100. Such mega-projects as the BDP2100, the majority of which are expected to be infrastructural, will likely entail considerable trade-offs.

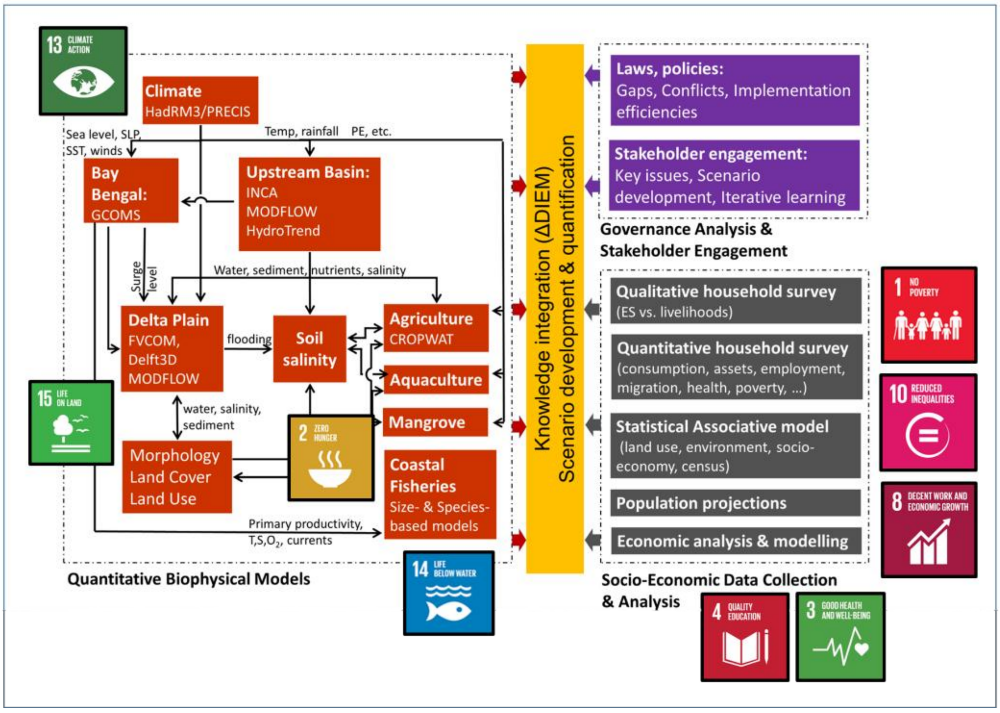

Figure 2. SDGs 1, 2, 3, 4, 8, 10, 13, 14 and 15 mapped to the ΔDIEM model framework (adapted from [16]).

3. Results: Case Studies of Potential Trade-Offs between the SDGs in Coastal Bangladesh

3.1. Case Study 1: Historical Economic Growth and Environmental Pressure on Resources

Perhaps the most well-rehearsed of the potential conflicts of interest between the SDGs is that of the growth of the economy. This is certainly the case in coastal Bangladesh where economic growth is still exacting a substantial impact on the environment by placing an ever-increasing demand on natural resources. The trade-off represented in Figure 3 is associated with the work of Hossain et al. (2016) [37] that showed increasing extractive elements of the system (food provisioning, water resources, and GDP growth) associated with increasing impacts on the environment (water quality and water availability (pre-monsoon)). Whilst at high levels of GDP per capita one might expect mitigation of these environmental impacts through decoupling of the environment from economic growth, for example, through the development of the service sector and the introduction of efficiency technologies, following the Kuznets curve hypothesis, this point has not yet been met in Bangladesh and the signs of extreme environmental degradation are present.

Hossain et al. (2016) [37] develop a straightforward non-modelled integration by a graphic, normalised comparison of a driver's set of parameters. Such an approach allows for a useful comparison of broad trends but without providing specific quantification or weighting. The clear message from this work shows that, since the 1980s, strategies to increase GDP in the Bangladeshi coastal zone have been associated with rising food and fish production levels, and an increase GDP by 17% (Figure 3), notwithstanding the limitations of GDP as a measure of poverty. However, this increase has come at a cost to regulating services such as water availability and quality (SDGs 14). This seems to be driven by an intensification of rice production, development of the service sector of the economy (such as tourism) and widespread conversion of rice fields to shrimp aquaculture. Although not certain, it seems that biodiversity maintenance, water availability and shrimp production (which generates its own potential for poverty increase), as well as enforced migration [24], seem to have passed a tipping point with the potential of a collapse in these services. Correlated with rising GDP in the coastal zone is rising risk, expressed as growing flood losses. Bangladesh is one of a set of Asian countries that are experiencing rapid economic growth whilst also being at high risk of natural disaster. As the value of the goods, services, and infrastructure grows, so does the consequent asset exposure component of risk. Despite considerable progress in reducing the number of fatalities caused by cyclones, Bangladesh must find ways to tackle the growing relative cost of disasters which is most heavily born by the poorest; those who are unable to access protection, both physical (e.g., those living outside the polders) and economic (those without access to affordable insurance) [38,39].

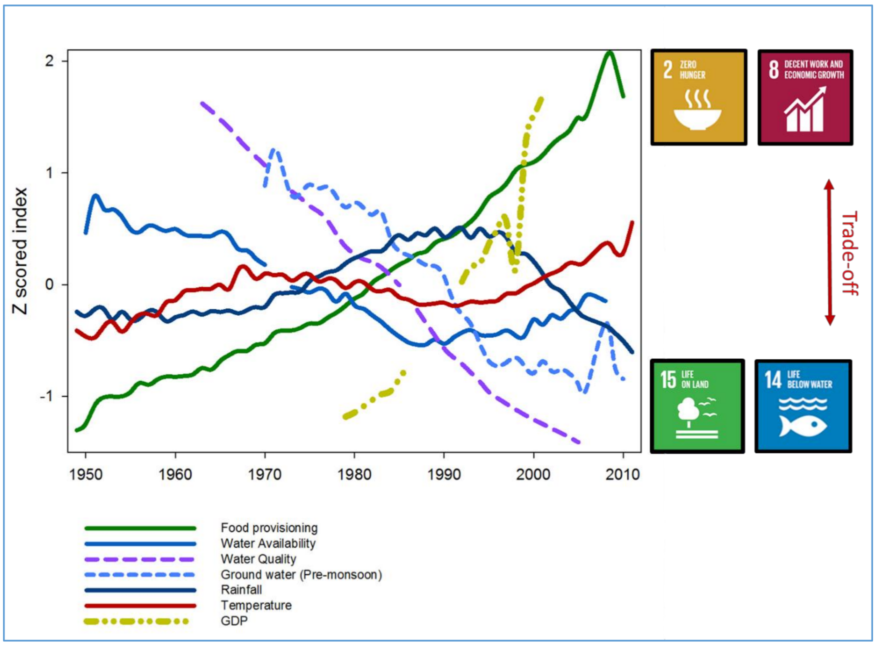

Figure 3. Modified from Hossain et al., 2016 [37]. Increased food production and development of the economy are in traded-off with a clear decline in ecosystem service provision.

This trade-off manifests itself over time and here centres upon which strategies are best deployed to maintain the reduction in poverty without further impact on the environmental services. A continuation of the current development trajectory might, with time, see a decoupling of economic growth from the increased demand on the environment (environmental Kuznets curve) which would alleviate the pressure on the regulating ecosystem services [40]. Equally, those same developments may increase the demand and thereby increase the use of those resources more than the decoupling reduces their use (Jevons paradox), ultimately leading to a collapse in those same regulating services, which would have substantial consequences. The important ethical questions here are then: Who will be affected? How (in their wellbeing, rights, freedoms, or autonomy), when and where do these consequences occur? Do we consider the distributional pattern over people, places and time fair? The outcomes of this work highlight that current generations may on the one hand have the responsibility to maintain a stable resource base for future generations, yet have the right to live a good life. To some extent understandably and indeed reasonably, it is rare that decisions are made at national policy level that intentionally and openly state to reduce or temper GDP growth. Indeed, the forthcoming Bangladesh Delta Plan 2100 emphasises economic growth whilst acknowledging the importance of preserving ecosystem services [37,40].

3.2. Case Study 2: Trade-Offs between Progressive and Traditional Farming

A critical trade-off between SDGs, specifically identified by Lazar et al. (2015) [30], is the value of progressive farming approaches vs. traditional farming methods. Progressive farming, currently only practiced in limited way in Bangladesh, deploys greater crop diversity and utilises improved technologies and approaches to a greater extent (e.g., new grain varieties, horticulture, and irrigation).

It is developed expressly to increase food security, tackle chronic hunger and potentially increase livelihood outputs (SDG 2: Zero Hunger and SDG 8: Decent work and economic growth) [18]. This approach stands in contrast to traditional farming approaches which are inherently less resource intensive and therefore have lower environmental impact (SDG 14: Life Below water and SDG 15: Life on land) [30] but generate less output as they rely on traditional, established technologies. Both approaches are supported by government in terms of implementation on the ground, subsidies, improved access to seed, etc. Progressive farming can be thought of as following two distinct approaches: (i) enhancing production of traditional crops such as rice through hybridization, genetically modified crops or access to effective irrigation; and (ii) diversification of crop type to try and capture income from high value markets such as high production rice and vegetables. The first approach involves a general trade-off between the requirements for substantial upfront investment, potentially resulting in a higher yield output at the end of the season. However, once a farmer is locked into this process, input costs can vary substantially and profits from yield can be subject to net price fluctuations [13]. As such, this represents a risky trade-off for farmers and planners.

The second approach, which relies on diversification of crops and is specifically modelled using ΔDIEM in Lazar et al. (2015) [30], offers potential benefits through the resilience of having multiple income streams. However, the susceptibility of some of the main diversification staples such as high value vegetables to climatic variance can result in substantial variance in year on year income compared to stable outputs from traditional approaches (Figure 4). Indeed, whilst it can be shown that, over an extended period, the net income from progressive farming is greater than from enhancing traditional crops (some 9% with 13% after 2033), the vulnerable farmers of Bangladesh are not in a position to be able to bridge financial shortfall from year to year without accruing often-unmanageable debt levels.

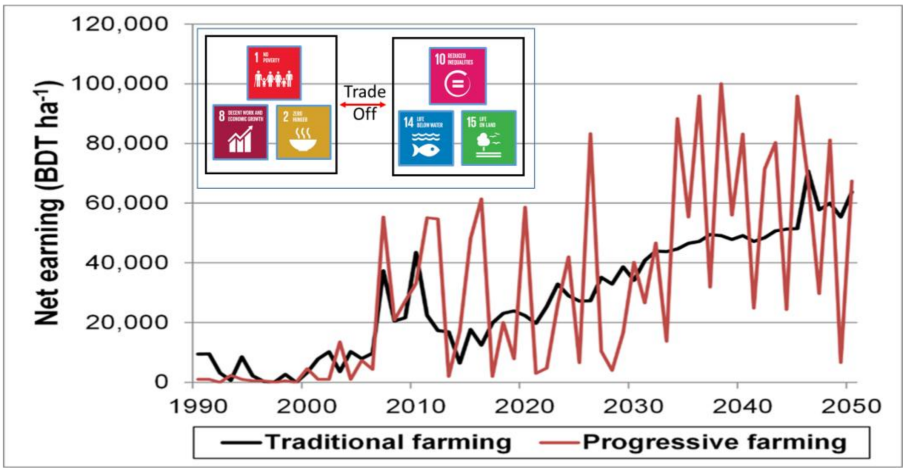

Figure 4. A graphic comparison of the modelled outputs of progressive farming against traditional approaches. Whilst the progressive approaches (fertilizer, improved crop patterns, and enhanced crop varieties) produce greater yield per hectare and hence great financial gains on average up to 2050, traditional approaches are more reliable from year to year. BDT is Bangladeshi Taka (after Lazar et al., 2015) [30].

As crop technologies become more developed, and the possible development of more resilient hybrids of vegetables, it may be possible to reduce the crops' climate susceptibility and therefore price fluctuation, but this may be offset in turn by the potential decline in prices as production of diverse crops increases. Further research is required to fully understand the trade-offs involved here (and not addressed in the original research), but the adoption of strategies to enhance food security and long-term livelihood-related economic growth at the farm level potentially, and perhaps counter intuitively, may conflict with the reduction in extreme poverty. Indeed, the process of developing progressive farming may indeed favour the wealthier farmers over the poorest and enhance the process of poorer farmers marginalisation. This is a good example of how a time variable integrated model can identify ethically significant trade-offs, at a ground level, that might otherwise not be considered in the broad development of the SDG strategies.

3.3. Case Study 3: Trade-Offs between Economic Development and Equity

One of the potential roles of an integrated model in assessing trade-offs within the policy decision-making processes is exploring the relative impact of different development strategies over time. Indeed, certain interventions and actions can have positive or negative impacts across one or more of the SDGs and across differing sectors of the community. The ΔDIEM model provides outputs across multiple indicators and, critically, through a series of decadal time slices. In Figure 5, it is possible to see a matrix of nine plausible ΔDIEM simulations of the future state of total assets (BDT, Bangladeshi Taka) for three specific livelihood types in coastal Bangladesh and for given climate change and sustainability management scenarios of the future. The three livelihoods represent three architypes (of 36 possibilities developed by the model): Dominantly Business (Large Land Owner), Dominantly Farmer (Small Land Owner) and Dominantly Farm Labourer (practically landless) as well as an average across all 36 archetypes (Figure 5) [16]. The information utilised in the model draws substantially on household surveys that surveyed 1586 households three times within one year and identified material, subjective and health dimensions of well-being in the context of natural resource use, particularly agriculture, aquaculture, mangroves and fisheries [25]. It is these findings, along with poverty work based upon the Bangladeshi Census in 2011 [31], that are then modified by the stakeholder weightings and perspective.

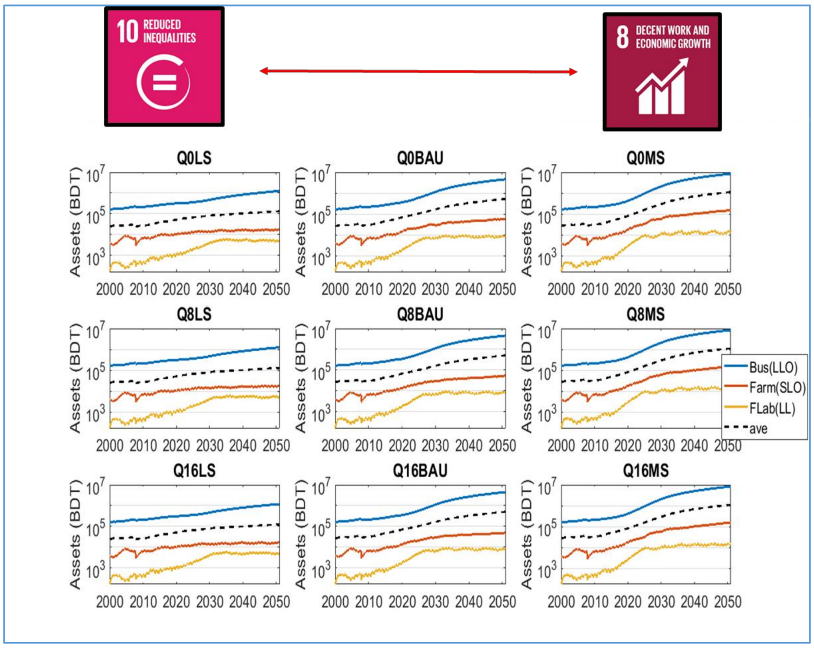

Figure 5. The income of three represented livelihoods architypes from 2000 to 2050. Dominantly Business (Large Land Owner), Bus (LLO); Dominantly Farmer (Small Land Owner), Farm (SLO); Dominantly farm labourer (practically landless), Flab (LL); Average household across all 36 archetypes, ave; LS, Less Sustainable; BaU, Business as Usual; MS, More Sustainable and are modelled from stakeholder/expert perceptions of future management of the delta including agricultural, socio-economic, hydrological, engineering and land cover variables. Q0, Q8 and Q16 represent progressively negative plausible modelled climate change temperature and precipitation outcomes Modified from [16]. Asset (BDT) refers to Bangladeshi Taka per annum.

For climate, three of the UK Met Office's HadRM3/PRECIS Regional Climate Model simulations (Q0, Q8, and Q16) are used to capture future climate variability under an A1B emissions scenario (RCP 6 Equivalent) [41]. Climate projections indicate a consistent trend towards increasing temperatures and precipitation over the region by the end of the 21st century. Heavy rainfall events are projected to become more frequent, with lighter and moderate rainfall becoming less frequent [41]. These projections feed into flood, drought and salinity projections across the study area that in turn affect crop production and livelihood outcomes [16,17]. These future states are moderated in relation to three potential states of sustainable management as defined by stakeholders. These are: (i) Less Sustainable; (ii) BAU; and (iii) More Sustainable, based upon demographic, cropping patterns and land and water management approaches amongst others (Table 2). BAU is defined as the situation that might exist if existing policies continue and development trajectories proceed along similar lines to the previous 30 years. LS and MS are alternatives that are broadly less or more sustainable than BAU. The scenario approach allowed us to take these two domains of interest and project how they might look in 2050 [16,17].

In the simplest sense, the bottom left of the matrix in Figure 5 represents the most pessimistic future state with the worst climate impact (Q16) and the least sustainably managed environment (LS). In contrast, the top right of the matrix in Figure 5 is the most optimistic future with the most benign climate change (Q0) and the most sustainable approach to policy development (MS). There are two critical interpretations of Figure 5. Firstly, when looking vertically through the matrix where the severity of change going forward is climatic only (A1B—Q0, Q8, and Q16) there are only small differences in asset outcomes for the three livelihood typologies. This is not to say that climate change is not happening, but that the difference *between* the climate scenarios is apparently not felt in the assets of the selected socio-ecological groups up to 2050. Beyond 2050, the specific global climate (including sea-level) scenario are predicated to become more dominant indicating why mitigation in climate change is critical for Bangladesh's future [41]. However, when the matrix is viewed across the rows, i.e., across management practices of land, water and demographics, there is a marked difference in asset level outcome. This suggests that socio-ecological policies, with their associated sustainability levels, are the dominant variable determinant of poverty and livelihoods at least until 2050.

The second critical point from Figure 5, is between the socio-ecological groups represented in the matrix. The most substantial change appears to be in the assets of the already wealthier business and large landowner group who seem to benefit disproportionally in comparison with the landless labourers. This can result in a net rise in overall asset income, but appears to be associated with an increase in inequality with very little growth in income for the poorest group of landless labourers. Why this relationship should exist is the subject of ongoing research into the details of the household survey and as such the model can be used to explore the rise in overall assets being associated with static or growing equity between the livelihood groups. These findings require further investigation, but demonstrate the potential to identify such policy trade-offs within an integrated assessment system.

4. Discussion

The case studies presented identify examples of the use of integrated approaches, both an IAM, and also a non-model based approach (Case study 1), in considering trade-offs between SDGs. In all the case studies presented, there is a trade-off between overall economic growth as might be measured by total change in GDP or agricultural outputs, versus the potential winners and losers associated with this process. In the first case study, the environment is the net loser to economic growth, which will have ramifications for those who are most reliant upon it, who are generally the poor. In the second and third case studies, there is a trade-off between the total monetary gain and the poorest members of society, who cannot access an equal share of benefits. Traditional farmers are unable to benefit from progressive approaches, as they do not have the capital reserves to weather the variability of the more progressive approaches. For reasons that are yet to be fully understood, even approaches described by stakeholders as more sustainable leave the poor with stagnant growth in relation to their wealthier peers.

Our examples clearly show how trade-offs are centred around justice, fairness and equity. The first case study highlighted that few countries opt to explicitly and intentionally reduce economic growth for the sake of maintaining stable resource stocks. In doing so, they are explicitly favouring SDG 8: Decent work and economic growth over SDG 14: Life below water and SDG 15: Life on land, even if that economic growth is, at least in part, as a result of the exploitation of natural resources. Moreover, whilst economic growth can positively affect SDG 1: No Poverty, evidence shows that growth is often not inclusive and poverty reduction is uneven across regions and sectors [42,43]. A sole focus on economic growth thereby fails to meet the SDG principle of "leaving no one behind", which is a critical trade-off with ethical underpinnings. Our examples furthermore demonstrate the potential for reaching tipping points that will see permanent economically significant loss, at the expense of natural resources [16,37]. As growth often benefits the wealthier groups relative to the poorer sectors of society, as expressed in Case study 3 (Figure 5), further ethical debates around inequality are likely to appear in policy processes related to the SDGs.

Clearly, these case studies are limited and are expressions of a nascent model in one of its first applications. Nevertheless, we have demonstrated that integrated systems models can, at the very least, elucidate decisions and be used to consider their potentially multiple ramification over both time and space. More specifically, it is possible to see that through the application of integrated systems models that address the issues of complexity and the interactions between socio-ecological and bio-physical variables, there is a high potential to address multiple trade-offs operating within one socio-ecological system and the SDGs represented therein. Clearly, there are caveats to this process. Firstly, systems-based models are diagnostic rather than deterministic, i.e., no single output should be considered as a prediction of the future. This needs to be addressed through: (i) always displaying multiple outputs as part of matrix of possibilities; and (ii) validation/verification as an important part of any integrated model approach [16]. Additional model limitations are gaps in the model components. These can be almost boundless at one level, the research team has prioritised further development as follows: (i) greater gender differentiation; (ii) more sophisticated economic representation; (iii) more sophisticated demographic treatment, including migration; and (iv) expanding geographic coverage of the model to elsewhere in Bangladesh. Despite these limitations, an integrated model such as presented here does offer a framework and method to use multiple cross-referenced approaches to understanding complex spatial and temporal trade-off between the SDGs with all the ethical issues that entails. As the model is developed, so the questions that might be posed can become more sophisticated.

5. Conclusions

There is a clear need to identify SDG trade-offs [44] and, given the urgency and primacy of the goals, and in line with adaptive management, this identification process should take place within project and programme work [4]. The model demonstrates that integrated modelling approaches can be valuable in exploring the relationships across SDGs and their drivers and outcomes, and supporting policy development of economic growth strategies with a broader range of beneficiaries. Our examples highlight that trade-offs can, directly but often indirectly, result in detriment to the poorest and most vulnerable. That the processes by which they lose out can be complex only reinforces the value of systems modelling. Solving the inherent value conflicts may require policy processes which are democratic, analyses that are transparent and procedures that address issues of value pluralism, complexity, basic assumptions, the relevant scope, scale and interactions, and the acknowledgement of context and history [42,45]. In such decision-making processes, quantitative models and their outcomes can play a crucial role when they are developed intentionally to elucidate sources of potential value conflicts and facilitate processes to solve disagreements over whose wellbeing should count, which SDGs matter and should be prioritised, or which losses are acceptable, through compromise or further negotiation. They are particularly useful when integrated with scenario analyses that are underpinned by robust scientific understanding of ecological systems whilst reflecting the plurality of values, beliefs and views on how to realise a good quality of life [46].

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