Opinion

Addressing sustainable development and climate change together using sustainomics

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This paper seeks to practically address two major global challenges—sustainable development and climate change. Developmental problems such as poverty are already formidable. Climate change is the ultimate risk multiplier, exacerbating the other crises too. Its worst impacts fall on the poor who are least responsible for the problem. The world currently faces multiple economic, social, and environmental threats. The economic collapse is the most urgent. The social crisis arises from global poverty, inequity, and inappropriate governance. Finally, mankind has caused severe environmental damage, including climate change. Present trends could destabilize global society. The way forward requires better use of economic stimulus packages to support green investments, social safety nets, and better price policies. A long-term vision goes beyond our current focus on surface level indicators. Instead, deeper issues need to be addressed systematically by focusing on both the immediate drivers and underlying pressures. The most effective approach is to integrate climate change policies into national sustainable development strategy, using the sustainomics framework. First is the practical, step-by-step approach of 'making development more sustainable' (MDMS). Second, we need a balanced and integrated analysis from three main perspectives: social, economic, and environmental. Third, the analysis must transcend conventional boundaries imposed by values, discipline, space, time, stakeholder viewpoints, and operationality. Finally, sustainomics provides many practical tools. This approach is applied globally to reconcile climate change risk management and development aspirations. Some practical national level applications are also described involving integration of adaptation and mitigation policies into sustainable development strategy. Specific cases include macroeconomic policy adjustment, sustainable pricing policies, renewable energy projects, and climate impacts on food security, agriculture, and water. Although the issues are complex and serious, both the climate change and sustainable development problems could be solved together, provided we begin immediately.
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INTRODUCTION

The global community needs to urgently and effectively address the two major challenges of the 21st century—sustainable development and climate change. On the development front, we already face formidable problems such as poverty, food security, sickness, and water and energy scarcities.[1,2]

Currently, about half the global population (3 billion people) survives on less than $2 per day. Almost a billion lack adequate food supplies and are malnourished—many of them children. Safe drinking water is not available to 1.4 billion, while some 2 billion lack adequate sanitation and access to electricity. Those who are sick, exposed to environmental degradation (air, land, and water), lack shelter, and are vulnerable to disasters, also number in the billions.

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Climate change is a major concern to everyone on the planet because it threatens to exacerbate these existing problems. Global warming is unequivocal and almost certainly caused by recent human activities that have increased the greenhouse gas (GHG) emissions.[3,4] It also indicates that climate change will likely intensify into the foreseeable future, with potentially disastrous consequences for the planet's inhabitants.

This article shows how the intertwined issues of sustainable development and climate change can be addressed together using the sustainomics framework.

RISKS TO CURRENT DEVELOPMENT PROSPECTS

The world is currently facing multiple economic, social, and environmental threats, which can interact catastrophically, unless they are addressed urgently and in an integrated manner—by making development more sustainable (MDMS).[5] Piecemeal responses have proved to be ineffective, as the problems are interlinked.

Economic, Social, and Environmental Threats

The economic collapse is the most urgent and visible global problem (Figure 1). An asset 'bubble' driven by investors' greed rapidly inflated the value of financial instruments well beyond the true value of the underlying economic resource base. The collapse of this bubble in 2008 caused the global recession.[6,7]

Figure 1 also shows major social problems such as poverty and inequity, which continue to undermine the benefits of recent economic growth, and thus excluding billions of poor from access to productive resources and basic necessities.[2] In 2000, the top 20 percentile of the world's population, by income, consumed 60 times more than the poorest 20 percentile.[8] Economic recession now exacerbates poverty, worsening unemployment and access to survival needs.

Finally, mankind faces major environmental problems, because myopic economic activities continue to severely damage the natural resource base on which human well-being ultimately depends.[9,10] Climate change is one major global outcome, but equally serious issue is the degradation of local water, air, and land resources. Ironically, the worst impacts of climate change will fall on the poor, who are not responsible for the problem.[3]

And what are our current policy priorities as we face these challenges? Governments have very quickly found about 5 trillion dollars for stimulus packages to revive shaky economies.[11] However, only about 100 billion dollars per year is devoted to poverty reduction, and far less to combat climate change.[2] The asset bubble far exceeds the annual global gross domestic product (GDP), while the high share of trade (>30%) in GDP underlines global connectivity that increases systemic risk. Annual military expenditures at 1.2 trillion are over 10 times larger than developmental aid. Furthermore, the recession has dampened the enthusiasm to address more serious sustainable development issues.

World leaders missed a golden opportunity to simultaneously address these multiple threats, by using the 5 trillion dollars of stimulus funds more effectively. A larger share could have been invested in key areas of green resources and infrastructure, especially renewable energy (as well as agriculture, water, and transport), sustainable livelihoods and safety nets for the poor, and social development (typically education, health, and safety), to stimulate the economy, increase employment, reduce poverty, and protect the environment (including the climate). Instead, funds were used to protect current expenditures and maintain subsidies. Although bank bailouts were necessary to prevent a far more disastrous financial crash, the risk remains that proposed banking regulatory reforms would not be sufficiently far reaching and merely restore the failed status quo. Only Korea and China who devoted 80 and 35%, respectively, of stimulus funds to green investments sought to use the momentum for long-term change—the corresponding figures for most other countries were under 10%.

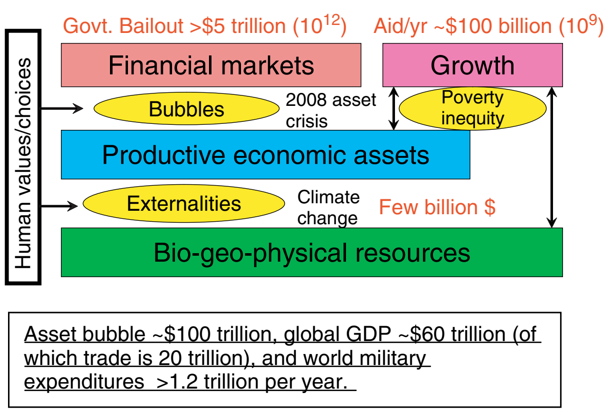

FIGURE 1 | Multiple global crises and human priorities.

Climate Change—A Potent Threat Multiplier

Climate change is a potent risk multiplier, which is systematically worsening the other crises described earlier. We briefly review the scientific facts below.[3]

Without serious emission reductions, carbon dioxide concentrations which exceed 385 parts per million by volume (ppmv) now will reach about twice the preindustrial level (i.e., around 550 ppmv) by 2100. The average global temperature will increase about 3°C above current levels, and the mean sea level will rise 35–40 cm. Extremes of temperature and precipitation will worsen, and the melting of ice will accelerate. Even if emissions were sharply curbed, temperatures would rise over 1.5°C by 2100.

The scientific evidence emerging during the past three years (after the IPCC Fourth Assessment Report) indicates worsening trends, with warming of *at least* 3°C and sea level rise of *at least* 50 cm by 2100, based on a business-as-usual scenario.[4] The recent Copenhagen Accord states that 2°C (corresponding to 400–450 ppmv) is the tolerable risk threshold, which implies that global emissions of greenhouse gases need to peak by 2020 at the latest, and decline thereafter.

The most vulnerable groups will be the poor, elderly, and children. The most affected regions will be the Arctic, sub-Saharan Africa, small islands, and Asian megadeltas. High risks will be associated with low-lying coastal areas, water resources in dry tropics and subtropics, agriculture in low-latitude regions, key ecosystems (like coral reefs), and human health in poor areas. Moreover, the magnitude and frequency of extreme weather events will worsen, especially tropical cyclones and heat waves. One major outcome of such impacts is that prospects for achieving many key millennium development goals (MDGs), which are already in some doubt, will become even more remote.[12]

LONG-TERM VISION FOR A BRIGHTER FUTURE

On the basis of the foregoing, Figure 2 shows a summary of a long-term vision. The top row recognizes that our current focus is on surface level indicators such as poverty, inequity, exclusion, resource scarcities and conflict, poor governance, and environmental harm, which are driven by powerful phenomena like globalization and unconstrained market forces based on the 'Washington Consensus'. We address different problems myopically and in a reactive uncoordinated and piecemeal manner. Therefore, present trends pose significant risks that could lead to a breakdown in global society, because of the ineffectiveness of governments seeking to cope with existing multiple, interlinked crises, exacerbated by fresh problems like climate change.

The second row in Figure 2 shows that an immediate transitional step forward is possible, by influencing key common drivers of change, including consumption patterns, population, technology, and governance. Because these drivers indeed shape the main issues in the top row, the transitional step will help address a broad range of issues in an integrated manner, thereby controlling global trends and managing market forces.

More broadly, using known practical measures that make development more sustainable today,

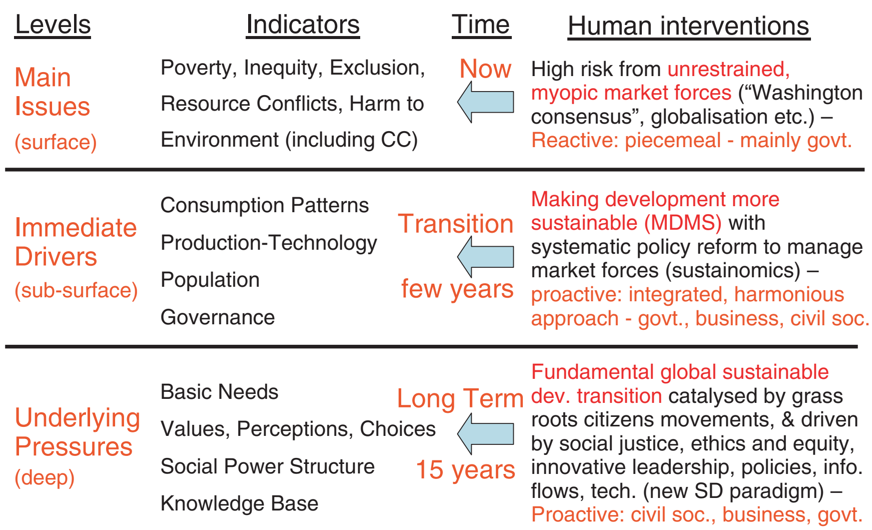

FIGURE 2 | Current risks and future vision. (Reprinted with permission from Ref 8. Copyright 2010 MIND Press.)

business and civil society could take the initiative to work with governments move proactively toward the ultimate goal of sustainable development. This networking approach would avoid overreliance on the alternative extremes of hierarchical (top-down) government control and unrestricted markets, both of which have not worked well.

The third row follows on from the successful implementation of the second (transition) row. Here, in coming decades our children and grandchildren might pursue their long-term goal of a truly global sustainable development paradigm. They would need to work on deep underlying pressures linked to basic needs, social power structure, ethical values, perceptions, choices, and knowledge base. Fundamental changes are necessary, driven by social justice and equity concerns, through inspired leadership, a networked, multistakeholder, multilevel global citizens' movement, responsive governance structure, improved policy tools, advanced technologies, and better communications (including the Internet).

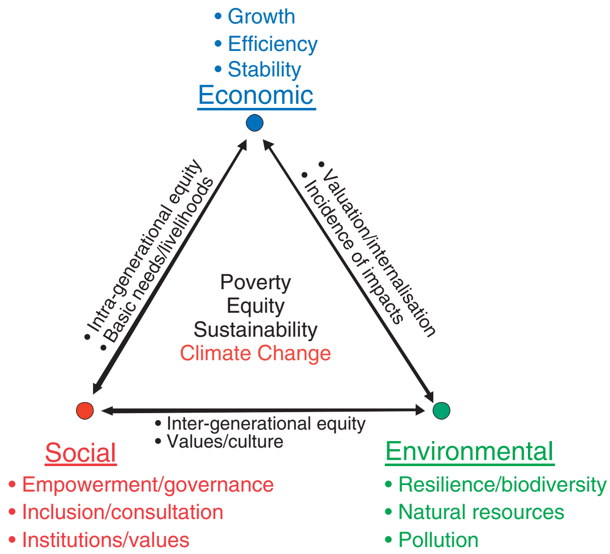

FIGURE 3 | Climate change and other issues are interlinked via the sustainable development triangle comprising economic, social, and environmental dimensions. (Reprinted with permission from Ref 13. Copyright 1992 World Bank.)

SUSTAINOMICS—A PRACTICAL FRAMEWORK FOR INTEGRATION

A key element of the transitional step 2 shown earlier in Figure 2 would be to break the destructive cycle between climate and development, by crafting strategies that address both the problems simultaneously. Decision makers are invariably preoccupied with immediate problems such as growth, poverty, food security, unemployment, and inflation. The best method of seizing their attention is to integrate climate change adaptation and mitigation measures into national sustainable development strategies. One practical way to do that, known as 'sustainomics', has been developed over the past 15 years.[8,13,14] It draws on the following basic principles and methods.

First, MDMS becomes the main goal. It is a step-by-step method that empowers people to take immediate action, which is more practical because many unsustainable activities are easy to recognize and eliminate—such as conserving energy. While implementing such incremental measures, we continue also parallel efforts to achieve long-term sustainable development goals. One key test for potential climate policies would be whether they would make development more (or less) sustainable.

Second, policy issues need balanced and integrated analysis from three main perspectives: social, economic, and environmental (Figure 3). Interactions among these three domains are also important. The economy is geared toward improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasizes the enrichment of human relationships and achievement of individual and group aspirations. Climate change is linked to all the three domains. First, economic growth drives emissions that cause climate change, whereas climate change impacts will undermine future development prospects. Second, climate has severe social implications, worsening poverty and equity. Third, climate change will exacerbate ongoing ecological damage, whereas environmental harm (like deforestation) will worsen climate. Win-win options which satisfy all the three criteria will best integrate climate and development. In other cases, judicious trade-offs would be required to resolve potential conflicts.

Third, we need to transcend conventional boundaries imposed by values, discipline, space, time, stakeholder viewpoints, and values. It is essential to replace unsustainable values like greed with sound ethical principles—this is a long-term task involving education, communication, and leadership, especially focusing on the young.[15,16] Transdisciplinary analysis is needed to find innovative solutions to complex problems of sustainable development and climate change that cut across conventional disciplines. Spatial analysis must range from the local to the global, typically from the community to the transboundary river basin and planetary scales. The time horizon needs to extend to decades or centuries. Cross-stakeholder data sharing, transparency, and cooperation (especially civil society and business working with government) need to be strengthened, by promoting inclusion, empowerment, and participation.

Finally, the sustainomics framework uses a variety of practical full cycle tools—both new methods and conventional ones. They are applied innovatively to encompass the full operational cycle from initial data gathering to practical policy implementation, monitoring, and feedback. Furthermore, life cycle analysis of the entire value chain is required, from raw material extraction to consumer end use and disposal, based on economic, social, and environmental perspectives (see Section below on integrating consumer and producer responses). This will help identify areas where innovation can improve production sustainability, reform pricing, and reduce carbon emissions because of business activities. It will not only identify the most desirable 'win-win' policies that simultaneously yield economically, environmentally, and socially sustainable paths, but also resolve trade-offs among conflicting goals.

Munasinghe[5,8] describes practical tools of sustainomics at the global and national levels, including integrated assessment models (IAMs), macro- and sectoral modeling, environmentally adjusted national income accounts (SEEA), poverty analysis, and the Action Impact Matrix (AIM—described below). At the project level, other useful methods for sustainable development analysis (SDA) are cost–benefit analysis (CBA), multicriteria analysis (MCA), environmental and social assessments (EA, SA), and environmental valuation. Some illustrative examples are summarized in sections *Global Level Integration, National Level Integration* and *Sectoral and Project Level Integration* below. At all levels, the choice of appropriate sustainable development indicators is also vital, derived from the basic economic–social–environmental metric.[18] The range of policy instruments includes both economic methods (such as pricing, taxes and charges, tradable permits, investments, and financial incentives) and noneconomic ones (such as regulations and standards, quantity controls, voluntary agreements, information dissemination, and research and development). More effective climate change communications are critical to motivate early action.[19]

GLOBAL LEVEL INTEGRATION

Addressing Climate Change—Adaptation and Mitigation Responses

Despite the 1992 UN Framework Convention on Climate Change[20] and the 1997 Kyoto Protocol, global GHG emissions continue to rise (e.g., more than 70% from 1970 to 2004). A series of annual UNFCCC meetings have not made adequate progress, most notably, with the weak, nonbinding 'accord' emerging from the Copenhagen Climate Summit in December 2009.

Sustainomics provides both a framework and practical tools for integrating climate change responses into sustainable development strategies.[3,14] Indeed, the existence of such an approach should help to dispel the concern of many policymakers that tackling climate change might divert resources away from more immediate development problems such as poverty and hunger.

The two specific ways that humans can respond to climate change are through adaptation and mitigation. Adaptation is aimed at reducing the vulnerability of human and natural systems to the impacts of climate change stresses. Mitigation seeks to lower GHG emissions or even absorb GHGs—to reduce radiative forcing of the atmosphere and the intensity of future climate change.

Present adaptation efforts need to improve. Natural organisms and ecosystems adapt autonomously, but many may not survive if the rate of change is too rapid. Humans carry out both preplanned and reactive adaptation. Proven adaptation methods like building dikes against sea level rise, and developing temperature- or drought-resistant crops, could be more widely implemented. Many similar technical, managerial, policy, and behavioral measures need to be adopted in both public and private domains, to increase long-term adaptive capacity of communities. The most recent estimates of global adaptation costs range from $25 to over $100 billion per year, during the next two decades.[21] Beyond that time frame, these costs could rise exponentially, especially if the assumed median warming is exceeded (2–3°C by 2100).

Current mitigation efforts also need to be improved—e.g., through increased energy efficiency and reafforestation. Such win-win options would not only lower GHG concentrations but also provide development benefits like improved health due to reduced air pollution, lower energy demand, greater energy security, and better energy availability for everyone. Known mitigation technology and policy options could stabilize GHG concentrations in the 450 ppmv range within the next 100 years, at a median cost of about 3% of world GDP by 2050.[3] More recent reports by Stern[22] and Garnaut[23] provide details of the economics of climate change.

Reaching a Global Consensus

The MDMS approach of sustainomics helps to outline a long-term consensus that would reconcile climate policy and development aspirations (Figure 4). On this stylized curve of environmental risk against a country's level of development, poor nations are at point A [low GHG emissions and low gross national product (GNP) per capita], rich nations are at point C (high GHG emissions and high GNP per capita), and intermediate countries are at point B.

The following elements are essential for a workable global compact on climate change:

- Industrial countries (already exceeding safe limits) should mitigate and follow the future growth path CE, by restructuring their development patterns to delink carbon emissions and economic growth, thereby making their development path more sustainable.
- The poorest countries and poorest groups must be provided an adaptation safety net, to reduce vulnerability to climate change impacts.

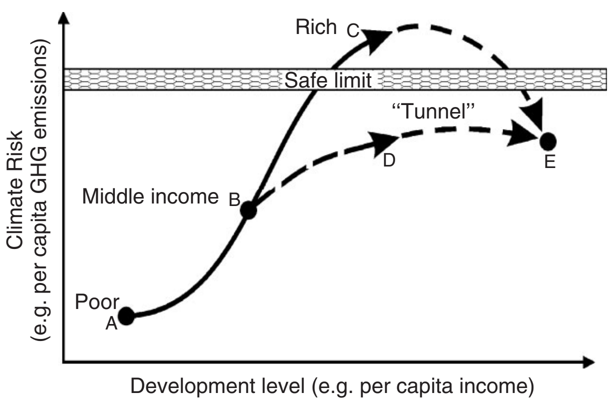

FIGURE 4 | Developing countries can 'tunnel' (curve BD) to avoid the carbon-intensive growth path of rich countries (curve BC). (Reprinted with permission from Ref 14. Copyright 2002 Inderscience Enterprises.)

- Middle-income countries could adopt innovative policies to 'tunnel' through (along BDE—below the safe limit), by learning from past experiences of the industrialized world.
- Developing countries should be encouraged (with technical and financial assistance) to simultaneously continue to develop (and grow) more sustainably, by following a growth path that is not only less carbon intensive but also reduces vulnerability to climate change impacts.

This approach accords with the ideas of equity and climate justice emerging from sustainomics. The great bulk of GHGs have been emitted by the rich countries (which are better endowed financially and technically), so they should lead the mitigation effort and also assist poorer countries in both adaptation and mitigation. The poor countries must focus on vulnerability and adaptation, as they will be most affected by climate change and need to increase energy use to alleviate poverty and promote development.

Integrating Consumer and Producer Responses using Life Cycle Analysis and Supply/Value Chains

The consumption of 1.3 billion richer humans ultimately accounts for some 75% of total GHG emissions. Instead of viewing them as part of the problem, they could contribute to the solution. Sustainomics shows how full life cycle analysis can better link business and civil society to make consumption and production more sustainable. Supply and value chain analysis is applied to capture the complete range of inputs and activities that firms and workers use to deliver products and services.[8,24] The approach describes all stages of production and consumption from conception to end use and beyond. Supply/value chains may be local or global, and spread over many firms.

Table 1 illustrates how this analysis can pinpoint key points for mitigation. In the case of light bulbs,

TABLE 1 | Life Cycle Analysis across Product Categories Showing Very Different Percentage Carbon Emission Patterns along the Supply/Value Chain (Reprinted with permission from Ref 17. Copyright 2009 University of Manchester.)

Raw Material Production	Manufacture Processing	Logistics Distribution	Retail	Use by Consumer	Recycling and Disposal
Light bulb (UK 11 W)					
2%		1%	1%	**95%**	1%
Orange juice (Brazil freshly squeezed 1 L)					
28%	19%	**47%**	5%	1%	0%
Milk (UK, National Tesco)					
76%	5%	4%	10%	3%	1%

95% of carbon emissions depend on consumer actions. Therefore, the best method of reducing emissions is to encourage energy conservation by changing the light switching behavior of people. For imported orange juice, the highest fraction of emissions (47%) occurs during distribution/transport, which offers the best potential for emission mitigation. For milk, emission reduction efforts should be focused on the raw material production (i.e., 76% emissions at the farm). Furthermore, similar analyses could be performed, focusing on other key sustainability indicators like energy, water, local pollutants, employment, etc.

This approach can build a 'virtuous cycle' of mutually supportive sustainable consumers and producers that would cut across national boundaries and vested interests, and ultimately strengthen the political will to implement sustainable policies. The focus on millions of better-off homes can yield quicker results with smaller capital outlays, and would complement the traditional top-down approach that relies on big investments by industry and government. The rich would set a better example that will enable the many billions of poor to emerge from poverty along more sustainable consumption paths.

There is no need to wait for new technologies, laws, or infrastructure. Consumers can be persuaded to behave more sustainably without lowering their quality of life. Tools include pricing, product labeling, and information. The advertising and psychological ploys that currently encourage greater consumption could be 'tweaked' to promote more *sustainable* consumption. A sustainability-oriented culture would emerge as social trends evolve over time—an encouraging example being the major positive shift in social attitudes toward smoking, during the past few decades.

NATIONAL LEVEL INTEGRATION

The second core principle of sustainomics, involving the sustainable development triangle, often leads to complex trade-offs. The examples below illustrate how such issues are addressed.

Macroenvironmental Analysis

In West Africa, rapid aggregate economic growth, promotion of timber exports, subsidies for land-clearing, and open access forests have combined to cause accelerated deforestation, thereby exacerbating rural poverty, harming the local environment, increasing GHG emissions, and worsening the vulnerability to climate change impacts.[25,26] Thus, growth-inducing macroeconomic policies (including structural adjustment) interacted with imperfections in the economy to cause both social and environmental damage. Such imperfections (like policy distortions, market failures, and institutional constraints) made private (market) decisions deviate from socially optimal ones. Implementing complementary measures (like eliminating land-clearing subsidies and enhancing forest protection) helped to address the social and environmental problems and improve mitigation and adaptation prospects, without reversing the growth-promoting macropolicies—a win-win outcome. In Figure 1, the bubbles representing asset overvaluation and environmental externalities arise from market imperfections. In Figure 4, the highly peaked path ABCE could result from such economic imperfections and environmental externalities. Corrective policies would help to reduce these distortions and permit movement through the sustainable tunnel BDE. Such a tunnel path is also more economically optimal (e.g., like a 'turnpike' growth path).

Sustainable Energy Pricing

Another sector-based example involves sustainable energy pricing that addresses the three elements of the sustainable development triangle. First, it would be *economically* efficient to set energy prices at long-run marginal cost. Second, adding *environmental* externality costs (appropriately valued), including a carbon tax, would further reduce energy use and mitigate GHG emissions. Third, from the *social* viewpoint, it would be equitable to earmark some of these tax revenues to help the poor who cannot afford to meet their basic energy needs, and to fund adaptation by those who suffer adverse impacts. Otherwise, simply raising prices would become an inequitable, unethical, and ultimately unsustainable solution—i.e., a way of rationing energy and reserving it for the rich, while worsening the plight of the poor. This same argument would apply to carbon taxes.

Kyoto Flexibility Mechanisms

Kyoto mechanisms include the Clean Development Mechanism (CDM), joint implementation, and emissions trading—which permit industrial countries to transfer some emission reduction obligations to other nations, in exchange for payments. Figure 5 shows the analysis of CDM within the economic–social–environmental framework of the SD triangle.

In a developing country, the incremental cost of the *environmental benefit* from planting a forest to absorb carbon would be only X (say \$20) per ton C. The absorbed carbon would be credited

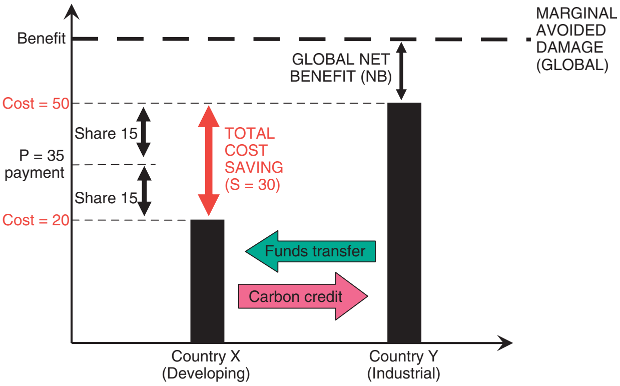

FIGURE 5 | Interplay of *economic* efficiency and *social* equity to reduce *environmental* harm from climate change. (Reprinted with permission from Ref 5. Copyright 2009 Cambridge University Press.)

to an industrial country, and set off against its own mitigation obligations under the Kyoto Protocol. Mitigation in the industrial country might otherwise have involved retrofitting an existing power plant at a much higher cost *Y* (say $50) per ton of carbon. This process would be *economically efficient* since the mitigation is performed at a least cost in the developing nation. Further, the transfer payment from a rich to a poor country would be *socially equitable*, provided the developing country received more than the minimum payment of $20 per ton C (to cover costs)—i.e., sharing the $30 cost saving. Recent compensation levels have ranged from $5 to 15 per ton C in developing countries, to about $20 within Europe.

SECTORAL AND PROJECT LEVEL INTEGRATION

Action Impact Matrix

Among the various sustainomics tools mentioned earlier, the AIM is a unique method that practically integrates climate change and sustainable development.[5,8] This approach has been used successfully in many countries. It identifies and prioritizes issues arising from the two-way interaction: how (1) the main national development policies and goals affect (2) the key adaptation and mitigation options, and vice versa.

The AIM methodology uses a fully participative stakeholder exercise. Up to 50 experts are drawn from government, academia, civil society, and business—representing relevant disciplines and sectors. They interact intensively over about 2 days to build an AIM. This participative process is as important as the product (i.e., the matrix). The synergies and cooperative team-building activities that emerge help participants to better understand opposing viewpoints, resolve conflicts, promote cooperation and ownership, and facilitate implementation of the agreed policy remedies.

Figure 6 shows a typical AIM for Sri Lanka in 2007. The first status row (S0) assesses the effect of natural variability (without climate change) on key climate change vulnerabilities, impacts, and adaptation (columns 1–10). The second status row (S1) shows how the onset of climate change will further affect each column—e.g., in column 1, the status of agricultural production will worsen from −1 (low harmful) in row S0 to −2 (moderately harmful) in row S1, due to climate change. The remaining rows A–G summarize how the main national goals and policies will be affected by the key vulnerabilities (columns 1–10), after climate change has occurred.

Any cells with values of −3 or −2, which indicate the more adverse effects, should have the greatest priority. Conversely, cells with values of 0 or 1 may be ignored because effects are minimal. Accordingly, looking down column 1, we see that climate change will have a highly harmful effect on food security through the agriculture sector, as indicated by the value of −3 in cell C1. Similarly, going down column 6, we note that cell C6 also has a value of −3, showing that the lack of water resources will also be highly harmful to food security. The AIM is built using an Excel spreadsheet, with each cell hyperlinked to another sheet describing details of why such values were given, including literature citations—e.g., the description for cell C1 describes outputs of all major crops in different parts of Sri Lanka, under different temperature and rainfall conditions.

In summary, the food security row C indicates cause for alarm, where both agricultural production declines and water resource shortfalls will have highly harmful impacts (matrix cells C1 and C6, respectively).

Agriculture, Water, and Food Security

Thus, the application of the AIM approach in Sri Lanka showed major climate vulnerabilities and impacts arising from food security, agriculture, and water. Accordingly, a more detailed study of this issue was carried out using a Ricardian agriculture model, to identify how past output changes in important crops such as rice, tea, rubber, and coconut had depended on natural variations in temperature and rainfall. Then, a downscaled regional climate model was used to make detailed temperature and precipitation predictions specific to Sri Lanka, up to year 2050. The combined results of both models showed that the impact

Notation
+ Beneficial
– Harmful
3 High
2 Moderate
1 Low

Key Vulnerabilities, Impacts and Adaptation (VIA)

		(1) Agric. Prod.	(2) Hydro-elec.	(3) Deforest-ation	(4) Bio-div.	(5) Wetlands & coast habitats	(6) Water resources	(7) Poor communities	(8) Health	(9) Infra-structure	(10) Industry & Tourism
(S0)	Status (Nat.	−1	0	−2	−1	−1	−2	−1	0	2	2
(S1)	Status (+CC Impacts	−2	−1	−2	−2	−3	−3	−2	−1	−1	−1
Dev. Goals/Policies (+CC Impacts)											
(A)	Growth	−1	−1	−1	−1	−1	−2	−2	−1	−1	−1
(B)	Poverty alleviation	−2	0	−1	−1	−3	−2	−2	−2	−1	−1
(C)	Food security	−3	0	−1	−1	−1	−3	−1	−1	0	0
(D)	Employment	−1	0	−1	0	−1	−2	−1	−2	−1	−2
(E)	Trade & Globalisation	−2	−1	0	0	0	−1	−1	0	−2	−1
(F)	Budget deficit	−1	−1	0	0	0	0	0	−2	0	−1
(G)	Privatisation	0	1	1	0	0	1	0	0	−1	−1

FIGURE 6 | Effects of climate change vulnerabilities, impacts, and adaptation (VIA columns 1–10) on development policies and goals (rows A–G) in Sri Lanka. The row S1 indicates how climate change will affect the status of VIA columns. The matrix cells in rows A–G indicate how the VIA columns will affect specific development goals and policies. The cells with a −3 ranking show the most adverse impacts, which need to be addressed. (Reprinted with permission from Ref 5. Copyright 2009 Cambridge University Press.)

on future rice cultivation would be negative and significant (almost 12% yield loss by 2050)—affecting poor farmers in the dry zone of Sri Lanka, where incomes are lowest. Meanwhile, some areas in the wet zone, where tea is grown and incomes are higher, would experience gains (+3.5% yield increase by 2050). Comparable results for agriculture in the Asia-Pacific region are provided in the study by Chang et al.[27] and Garnaut[23].

These findings raised several important policy issues.

- Rice is the staple food in Sri Lanka and a large portion of the population depends on rice farming. Thus, adaptation measures are essential to protect national food security, protect livelihoods, and reduce the vulnerabilities of the rural poor in the dry zone.
- The differential impacts of climate change on poor farmers and richer landowners have income distributional and equity implications also need to be addressed.
- Population movements from the dry to the wet zone are a potential demographic risk that policymakers need to anticipate and deal with early.

Multicriteria Analysis and Renewable Energy

MCA is another powerful sustainomics tool to assess sustainability indicators, especially when economic valuation of social and environmental effects is problematic. It allows policymakers to examine all the three elements of the sustainable development triangle (economic, social, and environmental) in a balanced manner—mainly by quantifying and displaying trade-offs to be made between conflicting objectives that are difficult to compare directly. MCA thus provides useful additional information to supplement economic CBA.

A second AIM was generated to study links between mitigation and development goals in Sri Lanka. Small hydropower was identified as a promising renewable energy option, raising the question of which small hydropower sites should be selected.

In the post-AIM detailed analysis, the mitigation potential of 22 specific small hydro sites was assessed in relation to three key sustainable development indicators.[5] The economic indicator was cost, the social indicator was number of people resettled (due to inundation of homes by storage dams), and the environmental indicator was a biodiversity loss index (also due to inundation of ecosystems). All indicators were measured per ton of carbon mitigated at each site,

TABLE 2 | Ranking Small Hydropower Projects According to Different Criteria

	Project Rank (A is Best)									
Indicator	A	B	C	D	E	F	G	H	I	J
Composite sustainability[1]	5	22	18	9	16	10	21	12	8	19
Social[2]	12	15	16	17	18	22	13	9	3	5
Environmental[3]	7	18	9	15	17	12	5	22	19	20
Economic[4]	5	22	8	18	9	16	10	21	12	19

Individual numbers from 1 to 22 stand for specific hydro projects, ranked A–J by impacts.
[1]The composite sustainability index is an MCA composite that gives equal weight to the social, economic, and environmental indicators.
[2]Social index measured by the number of people displaced.
[3]Environmental index measured by a composite biodiversity loss index.
[4]Economic index measured by cost.

assuming that each kilowatt hour of the hydroelectric energy generated would displace one kilowatt hour of fossil fuel-based generation and corresponding carbon dioxide emissions.

The row marked ‘sustainability’ in Table 2 shows the ranking of the top 10 projects (out of 22 examined). The project scores were based on a simple composite sustainability criterion, which gave equal weight to the economic, social, and environmental indicators—the best project being denoted by rank A. The next three rows give the ranking according to the three individual criteria (social, environmental, and economic). Clearly, the rankings change according to the criterion used. Thus, this analysis shows how results derived from the more balanced, sustainability-based approach using MCA would differ from rankings which relied only on a single criterion—e.g., like economic CBA.

Figure 7 shows how MCA can also provide a clear and intuitively appealing result. The three sustainable development indicators for these hydro sites are plotted in three dimensions, with the axes representing economic, ecological, and social objectives, respectively. The distance from the origin to each project point is critical. Generally, the closer to the origin, the better is the project in terms of achieving the three criteria. Then, ranking each project by its absolute distance from the origin, we find that the best five projects, from a sustainability perspective, are 5, 22, 18, 9, and 16 (also shown in the sustainability row of Table 2).

The MCA gives a clear assessment of hydro projects. It provides policymakers with a good idea about which project is more favorable from a balanced SD perspective. Thus, this approach provides intuitively appealing and robust results which will complement conventional methods like CBA, when policymakers wish to make decisions about integrating mitigation into national sustainable development strategy.

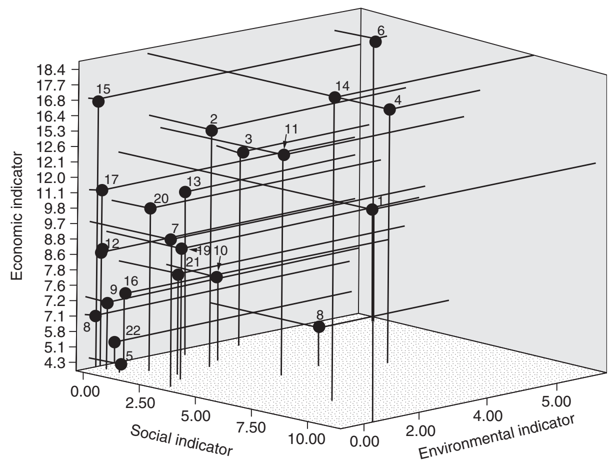

FIGURE 7 | Three-dimensional multicriteria analysis of the impact of small hydroelectric projects on sustainable development. Movement away from the origin along all three axes indicates worsening of the respective economic, social, and environmental indicators. Therefore, projects plotted closer to the origin are more desirable than the ones that are further away. (Reprinted with permission from Ref 5. Copyright 2009 Cambridge University Press.)

CONCLUDING REMARKS

Despite the problems we face, it is possible to conclude on an optimistic note. Climate change and sustainable development are interlinked problems that pose a serious challenge to humanity. Although the issues are complex and serious, both problems could be solved together, provided we begin immediately.

The sustainomics framework helps us to take the first steps toward MDMS, which will transform the risky ‘business-as-usual’ scenario into a safer future. The process showed us how to clearly identify the issues and threats (see section on *Risks to Current Development Prospects), define a fresh vision*, and transform our values (see section on *Long-term Vision for a Brighter Future*). Next, the paper briefly described a practical approach involving core principles, metrics (economic, social, and environmental indicators), analytical tools, and policy instruments (economic and noneconomic) (see section on *Sustainomics—A Practical Framework for Integration*). A growing number of practical applications of the approach are available at the global, national, sectoral, and project/local levels, and several illustrative examples were summarized in sections *Global Level Integration, National Level Integration,* and *Sectoral and Project Level Integration*.

A more active role was advocated for business and civil society, in moving us toward more sustainable production and consumption paths. Governments need to show greater political will and leadership by providing an enabling and motivating strategic policy framework that facilitates this process. This network-based approach avoids the risk of overreliance on the alternative extremes of hierarchical (top-down) government control and unrestricted markets.

MDMS requires us to first identify win-win options where improvements in all the three dimensions (economic, social, and environmental) are possible. Next, more complex trade-offs among the three objectives need to be analyzed and resolved in a way that simultaneously manages both development and climate risks. We know what to do. However, urgent action is needed along the lines set out in this paper, if human beings working together are to reenergize and reorganize themselves in time to plan, coordinate, and implement the necessary responses on a global scale.

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