Correction

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Correction for "Harvesting synergy from sustainable development goal interactions," by Matteo Pedercini, Steve Arquitt, David Collste, and Hans Herren, which was first published October 30, 2019; 10.1073/pnas.1817276116 (*Proc. Natl. Acad. Sci. U.S.A.* **116**, 23021–23028).

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Harvesting synergy from sustainable development goal interactions

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As countries pursue sustainable development across sectors as diverse as health, agriculture, and infrastructure, sectoral policies interact, generating synergies that alter their effectiveness. Identifying those synergies ex ante facilitates the harmonization of policies and provides an important lever to achieve the sustainable development goals (SDGs) of the United Nations 2030 Agenda. However, identifying and quantifying these synergetic interactions are infeasible with traditional approaches to policy analysis. In this paper, we present a method for identifying synergies and assessing them quantitatively. We also introduce a typology of 5 classes of synergies that enables an understanding of their causal structures. We operationalize the typology in pilot studies of SDG strategies undertaken in Senegal, Côte d'Ivoire, and Malawi. In the pilots, the integrated SDG (iSDG) model was used to simulate the effects of policies over the SDG time horizon and to assess the contributions of synergies. Synergy contributions to overall SDG performance were 7% for Côte d'Ivoire, 0.7% for Malawi, and 2% for Senegal. We estimate the value of these contributions to be 3% of gross domestic product (GDP) for Côte d'Ivoire, 0.4% for Malawi, and 0.7% for Senegal. We conclude that enhanced understanding of synergies in sustainable development planning can contribute to progress on the SDGs—and free substantial amounts of resources.

sustainable development goals | SDGs | synergy | integrated policy

The 2030 Agenda for Sustainable Development launched by the United Nations in 2015 provides a framework to guide global progress toward 17 sustainable development goals (SDGs) and 169 targets (1). These cover a broad spectrum of development issues relevant to all countries. The Agenda is innovative in that it recognizes the integrated nature of the SDGs and explicitly calls for policy integration.

Policy integration, often used interchangeably with policy coherence, refers to "policy making processes that take into account interdependences between dimensions and sectors" (2), in contrast to "silo planning" (3). In the context of the 2030 Agenda, policy integration entails the analysis and management of cross-sector impacts and synergies between policies directed to achieve the SDGs (4). Such analysis is valuable for designing suitable policies to reach the SDGs, estimating their costs, and valuing their global impact.*

Synergies arising from the interaction of policies, in which the aggregate impact is different from the sum of the individual impacts, may offer unique opportunities for cost-effective SDG strategies. In this paper, we present a framework with which to identify and quantify synergetic policy mixes for improving national SDG performance.

The synergies are generated by the dynamic interactions among system elements, which cannot be captured using a siloed, reductionist approach. To effectively analyze synergies, it is useful to adopt a quantitative representation of major development processes across the SDG spectrum. With such a quantitative model, multiple policies in different sectors can be simulated individually as well as simultaneously to assess potential individual and combined effects.

Method

A few frameworks have been developed to assist with conceptualizing the interconnectivity that characterizes the SDGs. The best known of these include the framework for understanding SDG interactions developed by the International Science Council (ICSU) (5, 6); the SDG network diagrams developed at United Nations Department of Economic and Social Affairs (UN-DESA) (4); and the SDG interlinkages tool developed at the Institute for Global Environmental Strategies (IGES) (7). These frameworks are useful for developing an initial understanding of the interconnections among the goals. The UN-DESA SDG conceptual network maps connections between SDGs and targets, showing how some targets connect to more than one SDG. This may help in identifying targets that are central in the network of SDGs, but the framework is purely qualitative and does not provide the means to quantify synergies. The ICSU framework attempts to provide some measure of the intensity of the relationships between SDGs on a −3/+3 scale. The scale can be thought of as a set of influence coefficients. For example, a +3 relationship indicates that progress on a dependent target or goal is strongly positively influenced by progress on another specific target or goal. Scores of +2 or +1 indicate that progress on a dependent target or goal is less influenced. A −3 score indicates that progress on the dependent target or goal is halted by progress on another target or goal; scores of −2 or −1 indicate more moderate negative influence. This semiquantitative scale can be useful to develop an understanding of the centrality of some of the goals

Significance

The sustainable development goals (SDGs) offer the global community a compelling vision and universally agreed-upon framework to achieve a sustainable and equitable future—but present a costly undertaking in the short term. Our research suggests that synergetic effects arising from appropriately designed policy mixes can bring significant cost savings and improve SDG attainment. Identifying and quantifying synergies requires innovative and unorthodox approaches to policy analysis such as those operationalized in our 3 pilots. The synergy assessment method and typology introduced in this paper are widely applicable, even though the patterns of synergies vary considerably between countries. Our pilot studies focus on national policy for the SDGs. Our approach is nevertheless generalizable to integrated planning at other scales and time horizons.

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*Analysis of cross-sector impacts and policy synergies should be reflected in countries' national development plans and reported in their Voluntary National Reviews (VNRs). An examination of the VNRs of the last 2 y reveals that, while the majority of reporting countries have established institutional arrangements to facilitate integrated planning (e.g., the creation of SDG coordination units), little progress is reported on comprehensive and integrated analysis of SDG strategies, and cross-sector policy coherence remains a challenge (38–40). The lack of quantitative approaches and tools for integrated analysis of SDG strategies makes this endeavor especially difficult.

for broader development. However, its significance for quantitative analysis is debatable—e.g., it is unclear whether 2 +1 interactions are equivalent to a +2 interaction: or whether a +1 and a −1 interaction would have a null effect. Also, such an approach may neglect synergies that take place at different stages of the intervention. The IGES SDG interlinkages tool is quantitative in nature, and maps and assigns strengths to complicated linkages between SDGs and targets for 9 different Asia Pacific countries. However, the IGES tool does not simulate specific policies over the SDG time horizon, and therefore cannot be used to assess synergies associated with policy mixes.

The Millennium Institute has developed the integrated sustainable development goal (iSDG) model for national-scale SDG planning. The iSDG model is a system dynamics-based model. As such, the behavioral patterns (i.e., how different system variables changes over time) are analyzed as the outcomes of complex systems in which variables are causally connected in feedback loops. The mathematical representations in the model, in the form of differential equations, are combined with interfaces that make the assumptions about causalities explicit (8–13). This transparent approach to modeling invites discussion about the actual underlying causal structure of national development planning—and enables simulation of various "what-if" scenarios. The iSDG model is accordingly designed to assist development planning by providing a credible representation of real-world development. iSDG, like its forerunner Threshold 21, is based on feedback loops between and within 3 main sectors that may be referred to as environment, society, and economy and governance. Documentation of the iSDG model structure is available on the Millennium Institute website (11). Also, a detailed description of the iSDG structure is provided by Pedercini et al. (14). Copies of mathematical models and accompanying data can be obtained from the corresponding author. For model validation, see the technical note on iSDG model validation in *SI Appendix*.

The iSDG model can simulate multiple policies individually and in aggregate, thus enabling the quantitative assessment of anticipated synergies among SDG policies (13, 14). Other development planning tools adopting a similarly integrated simulation approach include the Threshold 21, a system dynamics-based model, and the International Futures system, a hybrid systems–macroeconomic model (15, 16); however, to our knowledge, no other tool has the comprehensive coverage of the SDGs as does the iSDG model. These characteristics make the iSDG specifically useful in studying the anticipated effects of SDG policies across sectors in an integrated way. We have applied the iSDG model in 3 countries in sub-Saharan Africa (SSA) to analyze the potential nature and extent of synergies between policies for SDG progress. Based on these 3 cases, we describe in this paper a framework to guide and systematize synergy analysis in the context of SDG policies.

The structure of the paper is as follows. *Synergy—A Definition for SDG Analysis* describes the definition of synergy that we adopt, and the calculation method we use to estimate synergies, including relevant details on the iSDG model. *A Framework for Analysis of SDG Synergies* lays out our framework for synergy analysis. *Estimates from Pilot Studies* presents our results from the 3 pilot studies. Here, we demonstrate that SDG policies that harvest synergies have the potential to substantially reduce implementation costs. *Discussion* presents our conclusions and identifies promising directions for future research.

Synergy—A Definition for SDG Analysis

The term synergy, from the Greek word for "working together," is used in different fields such as biology, pharmacology, information science, and systems science. It has distinct connotations in different fields and travels under names such as emergence, cooperativity, symbiosis, coevolution, symmetry, order, interactions, interdependencies, systemic effects, even complexity and dynamical attractors (17). In most cases, it is used to convey the same fundamental concept: that a combination of different actions or elements strengthen each other, leading to a result that is greater than the sum of their individual impacts.

We have developed the following definition for synergy in the context of SDG implementation/intervention analysis: 2 or more interventions generate synergy when their combined implementation results in progress for an SDG that is greater than the sum of the individual impacts of each intervention. Dissynergy occurs when the combined interventions lead to smaller progress than the sum of their individual impacts. When multiple interventions are implemented, instances of synergy and dissynergy compensate each other to yield a net value. For ease of expression, we will use the plural form "synergies" to refer collectively to instances of synergy and dissynergy.

Synergies arising from the interactions of interventions implemented in diverse policy sectors indicate that the SDGs are part of a highly interconnected social–ecological system. Therefore, their existence may also represent an indirect measure of the interconnectedness of the policy system. An appropriate analytical approach that can identify the type and assess the strength of synergies would help to identify investment strategies that maximize the occurrence of synergy while minimizing dissynergy.

In economics, the analysis and quantification of synergies have been developed in the context of mergers and acquisitions from a financial and management perspective (18, 19). Also, the concept of synergies has been used to analyze the interaction of economic players and institutions in a network, as in "synergetics" (20, 21). In the case of development policy, analysis of synergies has been carried out, focusing on specific thematic areas (22) or on interactions between organizations (23). Differential-equation–based systems models, such as the International Futures system (16), the Threshold 21 modeling framework (24), and the World3 model of the Limits to Growth study (25, 26) are suitable frameworks with which to conduct dynamic analysis of synergies as they account for delays and allow for circular causality. However, to our knowledge, no broad, quantitative analytical framework is available to support analysis of potential synergies in the context of SDG policies at the time of this study. This may relate to the difficulty of measuring the actual synergies related to, in this case, different policies for development. Carrying out experiments is hardly possible on a scale that is relevant to the analysis, and is ethically debatable. Ex post, comparative studies of the performance of different countries' SDG strategies can be carried out to assess the contributions of synergies. Even then, as in much social science research, it would be difficult to avoid exogenous disturbances and meaningfully isolate the effects of individual policies to be able to measure their synergies. Also, many SDG interventions will only demonstrate their full impacts many years after they are implemented. However, findings that can guide SDG policies have practical relevance primarily a priori, when these strategies are being developed. We therefore use a model-based method to identify synergies—carrying out thought experiments by simulating different policies using an integrated simulation model. In this way, we can anticipate the effects of the policies. The models we use serve as "policy flight simulators" (27). With these, the simulated effects of different policies can be compared and "what-if" scenarios simulated (10, 12, 27).

Tools to calculate the anticipated contribution of synergies to progress on a given SDG target should respond to a series of criteria. First, the tool must be multisectoral, i.e., it must be able to represent policy implementation in different sectors within the same model structure—a necessary precondition to jointly analyze interventions in different areas. Second, the model sectors must be dynamically integrated, and share key structural components (such as the fundamental demographic, economic, and resource-related structures) to properly capture the combined impacts of alternative policies. Third, the tool must explicitly represent the mechanisms of policy implementation, to support the analysis of the dynamics through which synergies may arise. Fourth, the tool must encompass a broad range of SDG indicators, ideally covering all SDGs, to provide a comprehensive picture of where synergies may occur. The iSDG model complies with these 4 criteria, and we adopt it for our study.

We adopt a simple method for the calculation of synergies. First, we simulate a business-as-usual (BAU) scenario, in which no additional policy is introduced beyond those currently in place. We then simulate all relevant SDG policies (e.g., those included in a national development plan) individually and record the impacts on the SDG indicators used in the model, measuring the differences between the values generated by the policy simulations and the BAU simulation. Subsequently, we simulate all policies simultaneously and record their collective impact on the

SDG indicators. Finally, we calculate the differences between the impacts on SDG indicators recorded in the simulation of all policies combined and the sum of the impacts of the individual policies. Formulated as a mathematical expression, we calculate anticipated synergies as shown in the following equation; where Impact_c is the impact generated when jointly implementing all interventions, and Impact_i is the impact generated by the single intervention:

$$\mathrm{Synergy} = \mathrm{Impact}_c - \sum_{i=1}^{n} \mathrm{Impact}_i.$$

The resulting value can be positive (synergy), null, or negative (dissynergy). Synergy indicates faster progress toward the SDGs than the sum of individual interventions would suggest; a dissynergy indicates slower progress.

Besides understanding the value of synergies, to maximize the potential impact of combinations of interventions it is necessary to understand the source mechanisms of both synergy and dissynergy. The following section provides a framework to classify synergies based on the types of mechanisms from which they arise.

A Framework for Analysis of SDG Synergies

The quantitative assessment of anticipated synergies is fundamental to identifying combinations of interventions that are estimated to be especially effective versus others that may lead to slower than expected progress. However, harvesting synergetic potential through the design of effective SDG strategies also requires an in-depth understanding of the sources of synergies, which can be assisted by a model that captures these.

Identifying the stage in the intervention process during which synergies have the potential to arise is important for both synergy and dissynergy. For synergy, such knowledge is important to ensure that the necessary conditions are in place to harvest synergy when interventions are implemented. For dissynergy, a good understanding of the specific mechanisms at their root is important for design interventions to limit their occurrence. This implies intervening in the right place at the right stage of the implementation process.

To depict how synergies can arise from different causes during the implementation of an intervention, we use a simple results chain for a single intervention. This is a well-known tool for results-based management broadly adopted to assess the impact of development interventions (28–30). We identify 5 fundamental mechanisms at different stages in the results chain that potentially give rise to synergies (Fig. 1): type I, inputs; type II, enabling conditions; type III, target group, area, and institution; type IV, marginal returns; and type V, overshooting objectives (a special case of type IV).

Type I synergies arise from the change in the inputs, e.g., financial resources, available for the implementation of a given intervention caused by the implementation of another intervention. For instance, a microcredit intervention might lead to faster economic growth and thus to higher revenue for the government. That higher revenue can then be used to improve the coverage and/or quality of an intervention in another sector, such as health or education. In that case, we would observe a synergy for health and education-related indicators.

Type II synergies arise when the implementation of a policy intervention changes the immediate outcomes of another intervention by affecting its enabling conditions. For instance, a policy directed to build a more extensive road network may improve the enabling conditions for a food distribution intervention, facilitating the transportation of food aid by road. In such a case, we would observe synergy for food security-related indicators.

Type III synergies take place when an intervention in a given sector affects the target group of another intervention. For instance, an intervention directed to improve access to contraceptive methods could extend the proportional coverage of a vaccination intervention, as there would be fewer children to vaccinate. In that case, we may observe synergy for health-related indicators.

Type IV synergies appear when the cost-effectiveness of progressing on a target indicator changes as the level of the indicator improves, i.e., when related interventions are characterized by increasing or decreasing marginal returns. In the case of rural

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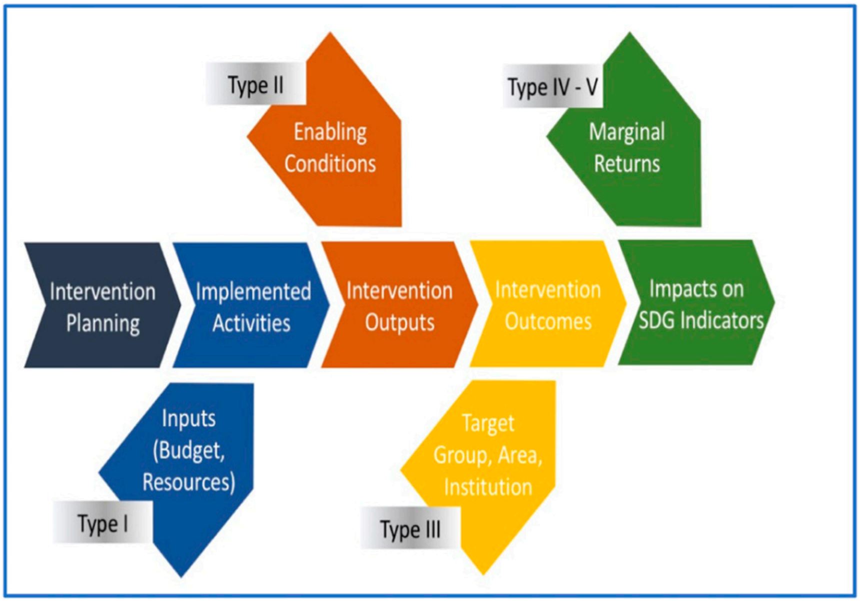

Fig. 1. Results chain for a single development intervention. There are 5 types of mechanisms at different stages of the chain that give rise to synergy. Type I synergies arise from interventions (e.g., financial investment) that increase the resources available for other interventions; type II synergies arise when an intervention creates enabling conditions for a second intervention; type III synergies arise when an intervention affects the target group of another intervention; type IV synergies arise when the cost-effectiveness of progressing on a target indicator changes as the level of the indicator improves; type V synergy occurs when progress on an indicator cannot, or should not, exceed a given target value.

access, for example, the marginal cost of reaching a person in a rural area would normally increase as people in less densely populated areas acquire access. Improving rail and road infrastructure might have both a positive impact on rural access in a given area, and good marginal returns if implemented in isolation to reach out to more densely populated rural areas. However, if rail infrastructure is first improved in the more densely populated areas, then to further increase rural access, road infrastructure would have to be developed in less densely populated areas. Since the marginal cost increases, the combined cost-effectiveness of the interventions would be reduced, generating a dissynergy. The dissynergy arises from the fact that the 2 policies have the same 'target audiences'—people in rural areas.

Type V synergies are a special case of type IV synergies; they arise when progress on an indicator cannot, or should not, exceed a given target value. That is the case, for instance, when an intervention designed to achieve universal (net) school enrolment (e.g., expanding the coverage of the school system) is combined with another intervention that could further increase school enrolment (e.g., improving public transport). Together, the 2 combined interventions could be more than enough to reach a level of school enrolment of 100%. In this case, all investments above the level at which 100% of enrolment is reached would have no effect on attaining the specific target. The marginal return would be equal to zero as school enrolment cannot exceed 100%. That mechanism can thus generate only dissynergies. In this instance, simulations with an appropriate model could help planners avoid overinvestment in the policies, preventing the potential dissynergy.

When simulating a large number of anticipated policy interventions, the generated net synergies can be determined by the combination of synergies of different types or polarities. In those cases, our analytical approach should be simulated incrementally: first including only pairs of interventions, and then gradually including more interventions until the full strategy is jointly simulated. By way of this process, not only the total net synergies can be appreciated, but a better understanding of the sources of those synergies can be developed.

A failure to understand possible synergies among policy interventions can easily lead to undesired results and suboptimal allocation of resources (24). The identification of the type of synergies that arise from the interactions of interventions is thus an important aspect to fine-tune policies and coordinate implementation, or in essence, to effectively harvest the synergetic potential of multisector strategies.

Estimates from Pilot Studies

In a first attempt to measure the contribution of potential synergies to progress toward the SDGs, we conducted pilot studies in 3 countries: Côte d'Ivoire, Malawi, and Senegal. We focused our pilot studies on SSA, a region where achieving the SDGs is especially challenging. In SSA, poverty levels are high, human development low, and resources for development interventions scarce. Côte d'Ivoire, Malawi, and Senegal are similar in their human development indices (0.474, 0.476, and 0.494, respectively) (31) and income levels: Malawi and Senegal are classified as low-income economies according to the World Bank Atlas method classification (32), and Côte d'Ivoire as a lower-middle income economy.

To perform a quantitative analysis of synergies, we use results from the iSDG simulation model (33), which was implemented and calibrated for the 3 countries. In all 3 cases, the model was developed using data from international databases (e.g., refs. 32, 34, and 35) and information sourced from experts within governmental planning institutions. The models underwent standard structural and behavioral validation tests for system dynamics models (36), including replication of historical data for key indicators over the period 1990 to 2015. A detailed description of iSDG model validation and testing is provided in *SI Appendix*.

For each country, we analyze performance for about 80 SDG targets under 2 different scenarios: a BAU scenario reflecting the current policies and budget allocation shares; and an SDG policy scenario, in which ambitious interventions to achieve the SDGs are simulated. In all 3 countries, the SDG policy scenarios have been designed in collaboration with the governmental planning institutions, to include as broad a range of policies to achieve the SDGs as possible. Nevertheless, these scenarios are not to be considered as reflecting an established development plan, but rather as a step in a reiterative and adaptive policy design process toward a gradual refinement of a development strategy.

We use the results from the 2 scenarios to assess anticipated synergies as described in the previous sections, based on the measured impact of each policy in the SDG scenario with respect to a BAU scenario. The performance of each SDG indicator is normalized with respect to a given target value that either is derived from the definition of the goal and target in the 2030 Agenda, or is estimated by experts from the local planning institutions. The performance on each indicator was then averaged to obtain the performance at the SDG target level; and performances at the target level were then averaged to calculate performance at the goal level. For further explanation of the calculation of SDG performance, refer to *SI Appendix*. The simulation results highlight important differences across the 3 countries but also significant similarities, as discussed in the following paragraphs.

Cross-Country Comparison of Results. The challenges to realizing the SDGs in the 3 countries are major, and the analysis of our BAU scenarios indicates that continuation on the current development path would lead to very low levels of achievement by 2030. In the case of Côte d'Ivoire, the simulated level of achievement is only 21% at year 2030 (Table 1). For Senegal and Malawi, levels of simulated SDG achievement under BAU assumptions are very low. In the case of Malawi, the BAU simulation indicates only 30% average attainment of SDGs by year 2030; in the case of Senegal, average attainment reaches only 29% by 2030.

Fig. 2 provides an overview of the contribution of each individual policy included in the SDG scenario on the progress toward achieving the 17 SDGs and of the synergies generated (highlighted in lavender color) for Malawi.

Fig. 2 highlights that, when simulated separately, many policies relevant to the SDGs have substantial cross-sector impacts. When jointly simulated, synergies generated from the interaction of those interventions are substantial. For cross-sector impacts and synergies for Côte d'Ivoire and Senegal, see *SI Appendix*, Figs. S3 and S4.

Fig. 3 shows and compares the contributions of BAU, SDG policies, and synergies. For simplification, all of the SDG policies are lumped together. The SDG policy mix varies between the 3 countries. Note that SDG policies can have both positive and negative influence on SDG performance. The black line with dots indicates SDG performance at year 2030.

In the case of the Côte d'Ivoire model, synergy is observed for 9 of the 17 goals, for an average contribution of the progress on each of those goals of about 13% and an overall average contribution across the 17 SDGs of about 7%. For the Malawi model, synergy is observed for 3 of the goals, with an average contribution of about 3% to each of those goals and an overall average contribution across the 17 SDGs of about 0.7%. For the Senegal model, we observe synergy for 6 of the goals, for an average contribution of about 6% to each and an overall average contribution across the 17 SDGs of about 2%.

Because synergy arises from combinations of interventions with different unit costs and effectiveness, the economic value of synergy is difficult to estimate. As a first approximation, we consider the percentage contribution of synergy to the overall improvement in performance across the 17 goals over the BAU simulations and relate it to the total cost of the simulated SDG

Table 1. Summary of SDG performance and synergies for the 3 pilot countries

	Côte d'Ivoire, %	Malawi, %	Senegal, %
Goals achievement—BAU scenario	21	30	29
Goals achievement—SDG scenario	67	59	61
Cost of simulated SDG strategy (% GDP per year)	19	18	11
Synergy—contribution to performance	7	0.7	2
Synergy—economic value (% GDP per year)	3	0.4	0.7
Dissynergy	10	8	4
Type V dissynergy	5	0.0	0.0
Other dissynergy	4	8	4
Economic value of type V dissynergy (% GDP per year)	2	0.0	0.0
Economic value of other dissynergy (% GDP per year)	2	3	1
Total saving from synergy and type V dissynergy (% GDP per year)	5	0.4	0.7

Goal achievement is the average achievement of the targets underlying the goal. The method for calculating goal and target achievement is explained in *SI Appendix*. Economic values are given in percent of GDP.

strategy. For the Côte d'Ivoire model, the total cost of the simulated SDG strategy is about 19% of gross domestic product (GDP) per year over 15 y, so that the economic value of synergy is in the order of 3% of GDP as shown in Table 1. For the Malawi model, the total cost for the SDG strategy is about 18% of GDP per year; the economic value of synergy is ~0.4% of GDP per year. For the Senegal model, the cost of implementing the planned SDG strategy is about 11% of GDP per year, and the economic value of synergy is thus 0.7% of GDP per year.

We also observe dissynergy for 7 goals in the Côte d'Ivoire model, for 11 goals in the Malawi model, and for 10 goals in the Senegal model. The dissynergy implies a simulated drag on performance of 10% on the overall SDG performance for the Côte d'Ivoire model, of 8% in the Malawi model, and of 4% in the Senegal model. Although the degree of dissynergy is alarming, the policy implications depend strongly on the type. While observed synergy is mostly of type I, II, and III, dissynergy is mostly of types IV and V, as discussed below.

Type I synergy is mostly evident through the simulated increase in domestic revenue observed in the SDG scenario, which is due to the acceleration in economic growth and the formalization of the informal sector. The increase in domestic revenue over BAU is as large as 3-fold for the Côte d'Ivoire model, about 1.7 times higher for the Malawi model, and 1.8 times larger for the Senegal model. The acceleration in the mobilization of financial resources from domestic sources facilitates a substantial

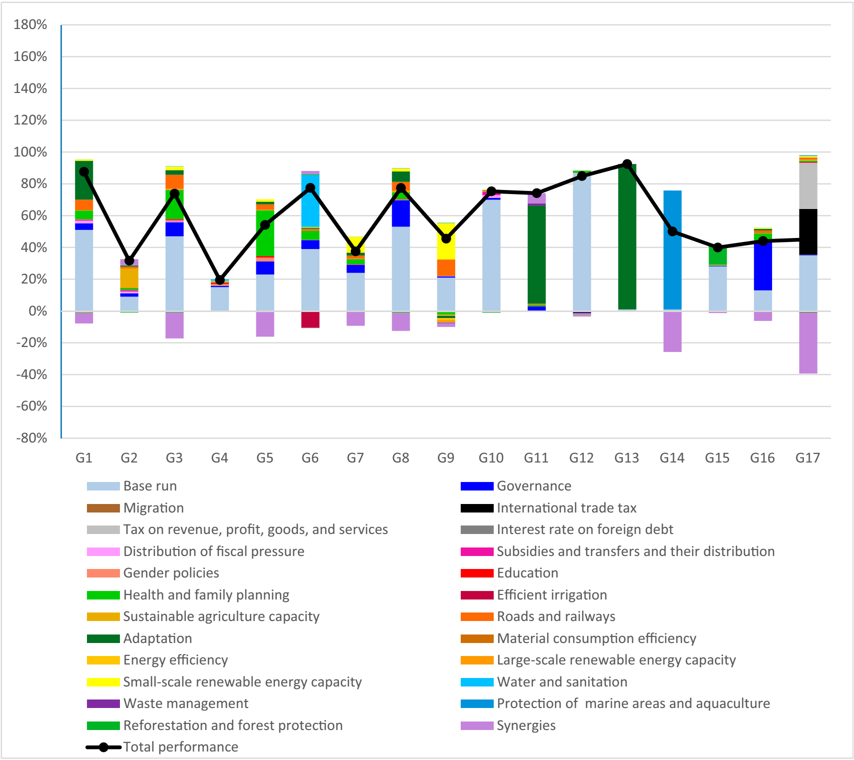

Fig. 2. Cross-sector policy impacts and synergies and summary chart for Malawi. The figure shows the influences of policies on all 17 SDGs at year 2030 Malawi, 1 of the 3 case studies. Business-as-usual (BAU) SDG performance is indicated in light blue. The performances of policies over or below the BAU when simulated individually are color-coded. The level of attainment for each SDG when the policies are simulated together is indicated by the black dots connected by the black line. Synergies (synergy and dissynergy) are indicated in light purple. The synergies represent the difference between SDG performances when all policies are simulated together and the sum of the policies simulated in isolation for each SDG.

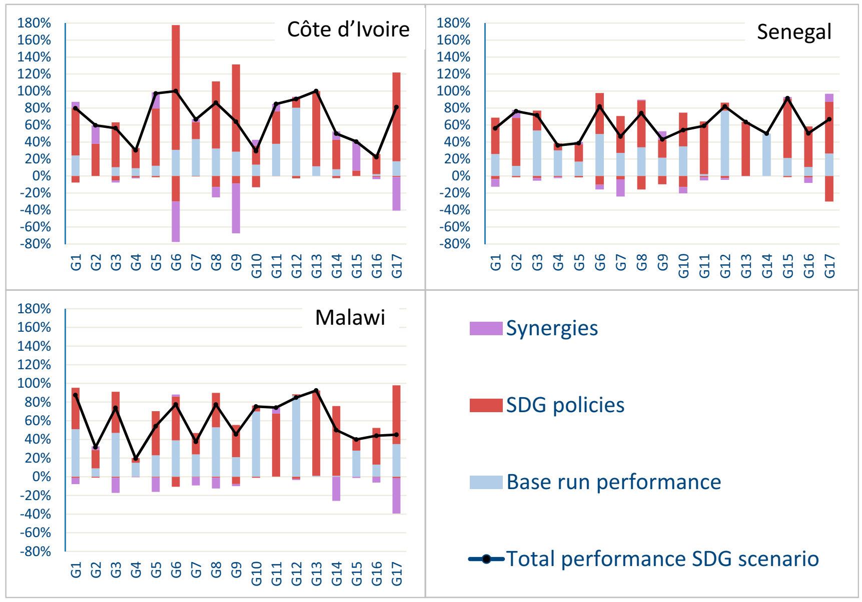

Fig. 3. Contributions to SDG attainment of BAU (base run performance), SDG policies, and synergies arising from policy interactions for Côte d'Ivoire, Senegal, and Malawi. The black line indicates the level of attainment of each SDG at year 2030. For simplification, the effects of the SDG policies are shown in aggregate. The SDG policy mix varies between the 3 countries. Note that SDG policies can sometimes exert a negative influence on some SDGs, e.g., expansion of irrigation for improvement of SDG2 could negatively impact water availability for human consumption (SDG6). The chart for Côte d'Ivoire exhibits instances of goal overshoot for SDGs 6, 8, 9, and 17, where the charts for Senegal and Malawi show all SDGs under 100% attainment. This is because the Senegal and Malawi cases have undergone several rounds of iterations to eliminate goal overshoot and redistribute resources to other SDG policies.

increase in public expenditure for the SDGs, while keeping the deficit under control and limiting the need for external support.

Synergy from enabling conditions (type II) appears to be strong in the 3 countries analyzed. Their current status of transportation and energy infrastructure, as well as education and governance indicators, suggest an unfavorable environment for implementation of SDG interventions. In the SDG scenarios, transportation infrastructure grows substantially faster in the 3 countries, leading to a paved-roads network 37% larger by 2030 for the Côte d'Ivoire model, more than doubling in the Malawi model, and 24% larger in the Senegal model. Similarly, energy infrastructure is more rapidly expanded in the SDG scenario, leading by 2030 to universal access to electricity (vs. 74% in the BAU) in Côte d'Ivoire, in Malawi increasing to 26% (over 6% in the BAU case), and in Senegal reaching 100% (vs. 93% in the BAU case). Education indicators also perform better in the SDG scenario than in the BAU scenario for all countries, leading to 12% higher average years of schooling by 2030 in the Côte d'Ivoire model, and 5% higher in the Malawi and Senegal models. Finally, governance indicators are assumed to increase substantially for the 3 countries, resulting in an overall improvement of 35% in the Côte d'Ivoire model, 76% in the Malawi model, and 40% in the Senegal model. Progress on those indicators, and especially on governance, generates strong improvements in enabling conditions in all of the 3 pilot countries, leading to synergy across SDGs. In the model environment, acting rapidly on enabling conditions achieves major savings in the implementation of SDG interventions.

Type III synergy in the 3 countries mostly derives from the overall slower growth in population observed when simulating the SDG interventions: Total population is about 16% smaller by 2030 than in the base run in Côte d'Ivoire, 8% smaller in Malawi, and 2% smaller in Senegal. The overall slower growth is the result of a simulated rapid decrease in births—due to both increases in income and education. The decrease in births is only partially compensated by a decrease in mortality, which leads to a slightly larger elderly population than would otherwise have been the case. Those results are in line with the findings from Abel et al. (37).

Dissynergy is observed for various goals in all of the 3 country models, mostly of types IV and V. Type IV dissynergy arises in many cases from the decreasing marginal returns that characterize interventions on infrastructure in the simulations. This is the case, for instance, for the dissynergy observed for Côte d'Ivoire and Senegal on goal 6 (on clean water and sanitation), and for Côte d'Ivoire on goal 9 (on industry, innovation, and infrastructure). In those cases, the marginal cost of extending the infrastructure gradually increases as the most cost-effective options are exhausted. Type IV dissynergy also arises for the 3 countries for goal 3 (on health and well-being). In that case, life expectancy increases to 68 y by year 2030 (vs. 60 in the BAU case) in the Côte d'Ivoire model, to 68 in the Malawi model (vs. 58 in the BAU case), and to 69 in the Senegal model (vs. 65 in the BAU case). As life expectancy increases because the leading causes of early death are eliminated, marginal return can approach zero as the cost of treating more complex diseases is higher. That type of dynamic calls for complementary interventions specifically designed to reach out to the most marginal areas or groups, who are especially difficult and expensive to serve.

For the Côte d'Ivoire model, the largest dissynergy is of type V. This dissynergy is especially ample for goals 6 (on clean water and sanitation), 8 (on decent work and economic growth), 9 (on industry, innovation, and infrastructure), and 17 (on partnerships for the goals). In all those cases, the sum of contributions of individual policies exceeds the 100% achievement limit, so that the excess performance represents a type V dissynergy. The simulated overshoot of objectives is due to the cross-sector impacts of interventions that, when properly accounted for, lead to far faster progress on SDG indicators than expected. Such phenomenon implies that excess resources can be reallocated to interventions directed to support other goals, bringing about a more homogenous SDG performance. In the cases of the Senegal and Malawi models, the SDG strategy has gone through several rounds of refinement and analysis through simulation; hence dissynergy of type V has been largely eliminated in the model environment.

If we account for type V dissynergy as a potential source of resources to be reallocated to interventions in other sectors, then a linear evaluation of the savings from synergy and type V dissynergy can account for as much as 5% of GDP per year in the Côte d'Ivoire model, and the remaining dissynergy to about 2% of GDP. For the Malawi model, synergy accounts for about 0.4% of GDP per year; the remaining dissynergy comes to about 3%. For the Senegal model, synergy accounts for about 0.7% of GDP, and other dissynergy for about 1%. Although these values are only a first approximation in the various simulations, they call for the importance of proper quantitative analysis of synergies in the context of the elaboration of integrated strategies to achieve the SDGs.

Overall, the simulations suggest significant variations in the impact of synergies on performance across the 3 countries. Globally, larger synergies are observed in the model for Côte d'Ivoire, and smaller synergies for Malawi and Senegal. The underlying reasons have to do with the different types of interventions simulated in the 3 countries, with the size of the interventions' budget, and with differences in the countries' socioeconomic structure as represented in the models.

Despite those differences, the possibilities in the 3 pilot countries for economic development, their lack of financial resources for implementing SDG policies, their initially poor enabling conditions, and their rapid population growth set the stage for strong synergetic potential. That may not be the case for mid- and high-income countries, whose economic and demographic development might respond less elastically to policy interventions and could thus exhibit weaker synergetic impacts. To develop a broader understanding of the potential importance of synergies in achieving the SDGs at the global scale, it would therefore be important to extend our analysis to countries from other income groups. In addition, our analysis is performed on individual country models, and therefore we do not account for synergies that can emerge from the interaction of policies that are implemented in different countries. We think that such synergies are becoming more and more important in the increasingly interconnected social–ecological system of our planet and should be further investigated.

Discussion

Our analysis based on simulations of combined SDG policies suggests that synergy can account for a relevant share of the progress toward achieving the SDGs (Fig. 3). We estimate the economic value of synergy in the simulated models to be 3% of GDP for Côte d'Ivoire, 0.4% for Malawi, and 0.7% for Senegal. Effectively harvesting synergy could free a substantial amount of resources for further SDG investment.

Dissynergy also impacts performance in the 3 country models. Some types of dissynergy are inherent to the nature of the interventions implemented in the models, while others can be more easily reduced. More specifically, type V dissynergy resulting from exceeding SDG targets is indicative of resources that could be more productively allocated to other sector policies through effective planning. By eliminating type V dissynergy, the total savings account for about 5% of GDP per year in our Côte d'Ivoire model. In the Senegal and Malawi models, type V dissynergy has been addressed in the development of SDG intervention scenarios, contributing to the development of more effective SDG strategies.

The identification and quantification of synergies could yield important opportunities to enhance SDG performance. Synergies arise because of fundamentally different phenomena, as described in the typology of synergies outlined in *A Framework for Analysis of SDG Synergies*. A correct understanding of the underlying sources of synergies is essential for effective leveraging of synergies in policy design. To this end, an integrated model that explicitly maps causal relationships within and across sectors, and that is capable of simulating the effects of multiple SDG policies both in aggregate and in isolation, is necessary. This is not to say that qualitative and semiquantitative methods, or other quantitative methods not using simulation, do not make important contributions to the understanding of SDG synergies; rather, insights from such research can inform and improve integrated simulation models and vice versa—the approaches complement one other.

Our analysis of policy synergies is based on results from models developed in pilot studies undertaken in 3 countries of SSA. From these studies, we expect that the synergies typology and assessment method introduced in this paper will be broadly applicable, while the results of synergies analyses will vary significantly for individual countries or regions. The extent of synergies depends on the strengths of the relationships between the social–ecological system elements, which can significantly differ across countries. In particular, we would expect different results between high-income countries and lower-income countries, due to, among other factors, the less dynamic economic and demographic conditions of the former. For effective policy analysis and planning, it is therefore important that all countries have access to appropriate tools for assessing policy options and their potential synergies.

A limitation to this research is that our study focuses on individual country models and does not account for synergies arising from the interaction of interventions between countries. This is appropriate for the SDGs as the 2030 Agenda mandates the SDGs at national scale. Regional and global synergy assessments are nevertheless promising areas of research and will be essential to building a more complete understanding of the relevance of synergies in the global effort to achieve the SDGs.

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