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Interactions between sustainable development goals at the district level in Lao PDR

Diana C. Garcia Rojas a,*, Jonas L. Appelt b, Michael Epprecht c, Michael Epprecht d, Sengchanh Kounnavong e, Chris Elbers a, Peter F. Lanjouw b, Jasper van Vliet b

a Department of Economics, School of Business and Economics, Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, Netherlands
b Environmental Geography Department, Institute for Environmental Studies, Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, Netherlands
c Centre for Development and Environment, Unit 11, #136, Simsawang Road, Hom 1, Ban Phapo, Vietsiane Capital, Lao Democratic People’s Republic
d University of Bern, Hochschulstrasse 6, 3012 Bern, Switzerland
e Lao Tropical and Public Health Institute, Samsenthai Road, Ban Angknot, Vietsiane Capital, Lao People’s Democratic Republic

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ABSTRACT

Monitoring the status and evolution of Sustainable Development Goals (SDGs) is typically carried out at the national level. However, significant variation can exist within countries, and this may not be captured by aggregate statistics. Here, we develop a unique dataset representing indicators for three SDGs at a district level for Lao PDR. The indicators comprise prevalence of stunting (SDG 2, Zero hunger), poverty headcount (SDG 1, No Poverty), and share of natural area (SDG 15, Life on land) for two moments in time: 2005 and 2015. In both years, we find considerable variation among district-level outcomes for stunting and poverty. We also find that higher stunting and poverty rates are significantly correlated with higher shares of natural land in both years. This is consistent with the common perception of a trade-off between environmental outcomes and socioeconomic wellbeing. The correlation vanishes, however, when we consider changes in poverty, stunting, and natural area over the ten-year study period. This holds as well when we focus on agricultural land instead of natural areas. We observe that most regions show improvements in both stunting and poverty, albeit not always in a statistically significant sense. This points to synergistic development. Similarly, improvements in both indicators are associated with losses in natural areas in all regions, indicating a trade-off. These results suggest that both trade-offs and synergies between SDGs can arise at the district level, but that context and local conditions likely moderate the strength of these interactions. Our results highlight the importance of quantifying and monitoring sustainable development at the detailed subnational level.

1. Introduction

A clear concern has surfaced since the formulation of the Sustainable Development Goals (SDGs) in 2015, regarding the existence of possible interactions among goals and targets. It has been argued that predicting the achievement of all goals is difficult as synergies and trade-offs amongst them are rarely given explicit consideration (Nilsson, Griggs, & Visbeck, 2016). In the SDG literature, synergies indicate positive interactions, in which movements of indicators are all in the direction of the same goals or targets. A trade-off, on the other hand, refers to the opposite, where one goal or target improves while another deteriorates. Several studies have identified the existence of both types of interactions using correlation analysis (Biggeri et al., 2019; Fusco Nerini et al., 2017; Nilsson et al., 2018; Scherer et al., 2018; Weitz et al., 2018).

Interactions between SDGs are typically explored and reported at a national scale, most likely because the progress of SDGs is generally monitored at the country level (Heck et al., 2018; Lusseau & Mancini, 2019; Mainali et al., 2018; Pradhan et al., 2017; Singha et al., 2021). The question arises whether and to what extent these findings can convincingly capture SDG interactions, as these are most likely to occur at the subnational level. However, monitoring sustainable development at the subnational level is challenging, especially in low-income countries, due to the challenges posed by collection of more granular data. National level indicators of household or individual welfare, as captured by poverty measures or nutritional outcome indicators, for example, are typically based on household surveys. These surveys are costly, resulting in limited spatial coverage. An alternative approach is to use small area estimates (SAE) to represent area-level data within countries (Lusseau, 2018; Lusseau & Mancini, 2019). SAE enables the calculation of statistics for smaller geographic areas, which can be used to infer interactions at the subnational level. However, the current practice of monitoring Sustainable Development Goals at the subnational level is typically based on household surveys. These surveys are costly, resulting in limited spatial coverage. An alternative approach is to use small area estimates (SAE) to represent area-level data within countries (Lusseau, 2018; Lusseau & Mancini, 2019). SAE enables the calculation of statistics for smaller geographic areas, which can be used to infer interactions at the subnational level.

E-mail addresses: d.c.garciarojas@vu.nl, dgarciarojas@worldbank.org (D.C. Garcia Rojas).

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in relatively small samples that are usually representative only at aggregate levels, such as states or provinces. This makes it challenging for policymakers to examine the status of SDG indicators and their interaction at the local level.

In the past few years, a new line of literature, as well as international action, has started to focus on SDG localisation. Even though international coordination was key to develop the SDGs, local action is still necessary because local institutions are the closest to individuals and have a better chance to generate collective action toward progress in each goal (Biggeri, 2021; Biggeri et al., 2018). For example, in OECD countries most policy regarding water, housing, transport, infrastructure, land use, among other relevant topics, is delegated to cities or regional governments (OECD, 2020). In response to this, several countries have developed bottom-up initiatives, referred to as Voluntary Local (or Subnational) Reviews (VLR/VSR), in which local actors, from government officials to different stakeholders, assess, monitor and present actions to implement the sustainable goals (Bilsky et al., 2021; Narang Suri et al., 2021). According to Bilsky et al. (2021), these tools have been successful by not only including diverse actors in the discussion, but also encouraging the use of more localized data, which stimulates local ownership.

Studies of trade-offs and synergies between SDGs frequently find synergies amongst socioeconomic indicators but find trade-offs when socioeconomic indicators are assessed against indicators of environmental outcomes (Bahar et al., 2020; Schmidt-Traub et al., 2017). Since agriculture is the dominant sector in terms of both employment and minimum subsistence in many low- and middle-income countries, land use plays a pivotal role in these observed interactions (Meyfroidt, 2018). Notably, an increase in agricultural land use is frequently linked to the reduction of both malnutrition and poverty. As a result, development policies often aim to intensify agricultural practices and raise productivity, especially in low- and medium-income countries. However, when this involves expansion of land devoted to agriculture this sometimes comes at the expense of natural area and biodiversity (Costanza et al., 2016; Marquardt et al., 2021).

According to the World Bank Group, Lao PDR’s international poverty rate in 2018 was 32.8 %, based on the poverty line of lower-middle-income countries. With a population of 7,425,057 in 2021, its GDP per capita was 2.536$, which places it as the third poorest country in Southeast Asia. In contrast to other countries in the region, Lao PDR has seen an increase in per capita arable land availability between 1995 and 2015. For this country, agriculture is the dominant development sector, accounting for around 65 % of national employment and 67 % of rural income. With low population growth, as well as an underdeveloped industrial sector, policies have attempted to encourage a shift from subsistence to commercial agriculture. This transition, which was pursued in multiple Lao National Socioeconomic Development Plans, has been key to achieving economic progress in the past decades (Asian Development Bank, 2017; National Rio +20 Report for Lao PDR, 2012).

Poverty rates based on national poverty lines fell from 39.1 % in 1997 to 18.3 % in 2018, while the Global Hunger Index fell from 52.2 % in 1997 to 25.3 % in 2018. The latter can plausibly be attributed to significant changes between these years. Based on international cross-country evidence, as well as findings from case studies in the region (Appelt et al., 2022), we hypothesize that there are synergies between stunting and poverty at the district level, and a trade-off between stunting as well as poverty, on the one hand, and natural areas, on the other. We also expect to find corresponding patterns between changes in stunting, poverty, and natural area over time.

2. Materials and methods

2.1. Estimating the prevalence of stunting

The method used for the estimation of prevalence of stunting in children under the age of 5 at the district level in Lao PDR is based on the small area estimation (SAE) technique developed by Elbers, Lanjouw, and Lanjouw (2003) (Elbers et al., 2003). The method uses common variables found in both a household survey and the population census collected around the same period. The survey data, which gathers information on household economic welfare (e.g., consumption and/or income) for a sample of a country’s population, is used to estimate a statistical model. This model is later applied to predict households’ economic welfare in the whole country using census data. Once this prediction is performed, aggregated indicators can be calculated for small areas (i.e. districts) and their precision assessed using Monte Carlo simulations.

We employ an adaptation of the small area estimation method described above, as developed by Fujii (2010), to include specifications more closely related to the estimation of child malnutrition (Fujii, 2010). The specific outcome predicted in this study is the z-score of height-for-age; an anthropometric measure used for the calculation of prevalence of stunting on children younger than five. Stunting is conventionally perceived to indicate the long-term nutritional status of children. Anthropometric measures are usually presented as z-scores because they are compared to the World Health Organization (WHO) child growth standards median. A child is considered stunted if his/her z-score is below −2 standard deviations away from the WHO child growth standards median. Therefore, once these z-scores are predicted for the whole target population, stunting rates can be estimated for small areas in the country, like districts or townships. More about the method can be found in Appendix A.1.

For Lao PDR, we used the Multiple Indicator Cluster Survey (MICS) from 2006 (Lao PDR Multiple Indicator Cluster Survey (MICS) 2006, 2006) and the Lao Social Indicator Survey II (LISI II) from 2017 (Lao PDR- Social Indicator Survey II (MICS-DHS) 2017, 2017), as well as the Population and Housing Censuses from 2005 and 2015 (Population and Housing Census 2005, 2015; Population and Housing Census 2015, 2015) to estimate stunting rates at the district level using these small area estimation methods. Additional, auxiliary data helped adjust the statistical model and comprised aggregated data from the Census of Agriculture 2010/11 (Census of Agriculture, 2010/11,2019), the Global Land Cover data developed by the National Mapping Organization (Kobayashi et al., 2017), the spatial limits of malaria transmission
estimated by the Malaria Atlas Project (Pfeiffer et al., 2018), and the VIIRS nightlights composite by NOAA (Elvidge et al., 2017). The statistical models estimated for children’s height-for-age in 2005 and 2015 for Lao PDR are presented in Tables A.1 and A.2. We should point out that the data underpinning these estimations are only available on an occasional basis. Notably, the population census in Lao PDR is fielded only every ten years (the Census databases). The analysis in this paper is thus only able to draw on predictions for two moments in time (2005 and 2015).

### 2.2 Estimating poverty headcounts

Poverty headcount rates for Lao PDR were estimated for 2005 and 2015 at the district level using the ELL method by Epprecht et al. (2008) and Pimhidzai et al. (2016), respectively (Epprecht et al., 2008; Pimhidzai et al., 2016). We selected the poverty measure using national poverty lines instead of an international poverty line since we aimed to compare poverty within Lao PDR. However, to evaluate poverty changes at the district level, it was necessary to adjust the poverty estimates for the year 2005 to account for the geographical changes in administrative boundaries that occur within the ten-year period. Between 2005 and 2015, there was an increase in the number of districts in Lao PDR, from 139 to 148 (Pimhidzai et al., 2016). Therefore, we used the administrative boundaries of 2015 to recalculate the 2005 estimates using the outcomes from the villages that were located within the new boundaries.

### 2.3 Quantifying land cover shares

The characterization of natural area was performed using land cover data previously collected by the SERVIR-Mekong initiative on the Regional Land Cover Monitoring System for the years 2005 and 2015 (Potapov et al., 2019; Saah et al., 2020). The categories of land covers for Lao PDR defined in SERVIR Mekong are Surface Water, Forest, Orchard or Plantation Forest, Evergreen Broadleaf, Mixed Forest, Urban and Built-Up, Cropland, Mining, Barren, Wetlands, Grasslands, Shrublands, Aquaculture. The land covers we selected to represent natural area were Forest, Evergreen Broadleaf, Mixed Forest, and Wetlands. However, Wetlands comprises only about 3.5 % of the natural area in both 2005 and 2015, and hence natural areas are mostly forests. These classes were considered to comprise the most biodiversity-relevant and green areas in the country. While some natural grassland exists at higher altitudes in Lao PDR, it can be assumed that all new grasslands in fact reflect agricultural activities, such as abandoned fields used for swidden cultivation (Q. Nguyen, personal communication). Despite finding similar results using only forest areas, we preferred to include all areas covered with biodiversity habitat, as this is closest to target 15.1 which aims to conserve and restore terrestrial and freshwater ecosystems. Also, we use natural area per capita, instead of the percentage of natural area, whenever comparisons were made with the socioeconomic indicators, which have already been standardized by population.

### 2.4 Analysis of interactions between indicators

We analyze the relation between our three SDG indicators for 2005 and 2015 using Pearson’s correlation coefficient. These correlations are interpreted as potential synergies and trade-offs, depending on the sign of the correlation and the interpretation of the SDG. We also use Pearson’s correlation to analyze the relations between changes in SDGs over time. The latter is not entirely consistent with the interpretation of synergies and trade-offs, as two indicators could improve in all regions (indicating a synergistic development) without any significant correlation in the district-level changes. Therefore, we also present potential synergies and trade-offs between pairs of SDGs simply based on the interpretations of the directions of changes in two indicators.

District-level poverty and nutrition outcomes are not observed or estimated from data directly but are predicted based on statistical models. Essentially, such predictions are determined by a given set of observed variables and, being predictions, are subject to error. It is conceivable that these prediction errors are driven by other determinants of poverty and nutrition, which are independent and additional to the set of predictors we use. This could systematically counter or weaken our findings on the correlations between district-level outcomes. While we recognize this possibility we do not think this a likely scenario, given the scrutiny that goes into validation of the statistical model underlying the poverty and nutritional predictions. For instance, when comparing the MICS and LSIS stunting estimates at the province or the regional level to our small area estimates, we find that average estimates are very close. For more information on the validation procedures we have employed, see Appendix A.3.

### 3 Results

#### 3.1 Status and change of SDG indicators

The estimated prevalence of stunting at the district level ranges from 15 % to 56 % in Lao PDR in the year 2015, as compared to a national rate of 35.5 % (Fig. 1A). These numbers are down from a range of 22 % to 63 % in the year 2005, corresponding to a national rate of 47.7 % (Fig. 1D). We find that changes at the district level vary from an insignificant change to a 29 percentage point decrease (Fig. 1G), and that districts with a higher prevalence of stunting in the year 2005 have seen on average a larger decrease in stunting (P < 0.01, Fig. B.1-A). While there is a decrease in stunting rates in all districts, those in the southern provinces display a greater reduction of malnutrition compared to the northern provinces. This is the first and most current disaggregated portrait of prevalence of stunting for Lao PDR.

SAE-based estimates of the prevalence of poverty at the district level in Lao PDR ranged from 5 % to 73 % of the respective populations in the year 2015, compared to a range of 6 % to 75 % in 2005 (Figs. 1B and 1E). At the national level, the prevalence of poverty fell from 27.6 % in 2005 to 23.4 % in 2015—a decline of just 4 percentage points. However, changes in district poverty rates vary from a 14 percentage points increase in the Lakhonepheng district to a 38 percentage points decrease in the Sanxay district, and in several districts, there is no significant change in poverty (Fig. 1H). As with stunting, poverty rates generally fell more in districts with higher base-year poverty headcounts in 2005 (P < 0.000, Fig. B.1-B).

Most of Lao PDR is covered by natural vegetation, that is Forests, Mixed Forests, Evergreen Forests, or Wetlands, in both 2005 and 2015 (Figs. 1C and 1F). Apart from a few districts located near the border with Thailand, most districts have a natural area coverage of 75 % and higher. In all districts of Lao PDR natural area coverage declined between 2005 and 2015, ranging from a fall of less than 0.5 percentage points in the Nongua district to a 29 percentage point decrease in the Xayabury district (Fig. 1I). At the national level, natural area cover decreased by 1 percentage point, with the highest loss concentrated in 4 out of 18 provinces. Generally, districts with a higher share of natural land cover in 2005 saw a larger decrease over time (P < 0.000, Fig. B.1-C). In the ten-year period studied, 94 % of natural area remained unchanged and 5 % changed from one type of natural land cover to another. Land cover conversions leading to a loss in natural area represent over 214,000 ha. Around 75 % of this conversion arises from changes from forests to land covers associated with agricultural activities, such as Orchards and Plantations, Cropland, and Grassland (Fig. C.1).

#### 3.2 Correlation between indicators

We find a significant positive correlation between stunting rates and poverty headcounts at a district level in both 2005 and 2015. Consistent with the notion that socioeconomic outcomes are largely dependent on agricultural activities, we also find a significant positive correlation in
Figure 1. Status and evolution of SDGs at district level. A-F: Stunting rates, poverty headcounts, and the shares of natural area in districts of Lao PDR for 2005 and 2015. G-I: Change in percentage points of stunting rates, poverty headcounts, and the shares of natural area from 2005 to 2015 at the district level in Lao PDR. Note: Provincial boundaries are indicated for spatial reference, while colors indicate district-level results. Changes in stunting and poverty indicated as ‘Not statistically significant’ are identified using a one-tailed t-test at the 90% confidence level. Representation of these indicators in 3D graphs can be found in this link. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
3.4 Potential interactions between indicators in specific areas

For Orchard/Plantation Forests or Grasslands. In the case of Fig. E.2 portrays how lower levels of Cropland area per capita are statistically significant at: \( p < .001 \), \( p < .005 \), \( p < .01 \), \( p < .05 \), \( p < .1 \), \( p < .001 \), \( p < .005 \), \( p < .01 \), \( p < .05 \), \( p < .1 \), \( p < .001 \), \( p < .005 \), \( p < .01 \), \( p < .05 \), \( p < .1 \), \( p < .001 \), \( p < .005 \), \( p < .01 \), \( p < .05 \), \( p < .1 \). Notably, plantations are as closely associated with lower poverty, agricultural area, and stunting rates than between poverty and natural area, especially for 2005. In contrast to the correlations between the status, or levels, of these indicators, we do not find any statistically significant association between changes in stunting, changes in poverty, and loss of natural area per capita between 2005 and 2015 (Table 1).

Despite the absence of statistically significant correlations over time, we do find evidence of synergies and trade-offs based on the analysis of directions of change only (Fig. 2). Specifically, we find that 94 out of 148 districts saw a statistically significant reduction in poverty and stunting between 2005 and 2015, indicating that these trends are synergistic in most of the districts. We also find that 82 % of the districts experienced a decrease in stunting alongside a decrease in natural areas per person, while 63 % saw both poverty falling and a decrease in natural areas per person.

3.3 Role of agricultural land use

Development of agricultural activities is often the assumed link between changes in stunting and poverty headcount on the one hand and change in natural area on the other hand. When we repeat our analysis with agricultural land (Cropland, Grassland, and Orchard/Plantation Forests), instead of natural area, we find that larger agricultural land per capita is indeed significantly associated with lower stunting rates, a relationship that becomes more prominent in 2015 (Figs. E.1-A and E.1-B). This is not as obviously the case with poverty rates, however, in either of the two years (Figs. E.1-C and E.1-D). Further inspection of their geographic location indicates that districts in the southern region of Lao PDR, such as the districts located in the provinces of Savannakhet, Salavan, and Attapeu, have the highest levels of agricultural land per capita as well as highest poverty rates, while at the same time, they also have the lowest stunting rates in 2015.

When we focus on Cropland only, the relationship with the socioeconomic indicators aligns more closely with our prior hypotheses. Fig. E.2 portrays how lower levels of Cropland area per capita are significantly associated with higher poverty and stunting rates in 2005 as well as in 2015, although again the relationship is more prominent with stunting. In Figs. E.3 and E.4, we can see that the relationship is opposite for Orchard/Plantation Forests or Grasslands. In the case of poverty, our evidence, therefore, suggests that not all agricultural activities – notably plantations – are as closely associated with lower poverty.

Again, as was also found above in the case of natural land area per capita, we find no relation between changes in agricultural land or in any specific type of agricultural land use on the one hand, and changes in stunting or poverty on the other hand (Fig. E.5).

3.4 Potential interactions between indicators in specific areas

Scrutinizing the changes in stunting, poverty headcount, and natural area at the district level reveals potential localized synergies and/or trade-offs that merit further inspection. Fig. 3 presents a bivariate map highlighting four districts in which poverty and stunting fell but with different degrees of natural area loss. Xaisane district (Attapeu Province) and Xaysathan district (Xaignabouly Province) are examples of local areas with potentially strong synergetic associations between the socioeconomic indicators and a weak potential trade-off with the environmental indicator, while Xaybuly district (Savannakhet Province) and Xaysetha district (Attapeu Province) are examples of areas with stronger potential trade-offs. It should be noted that within Attapeu Province we find above-average declines in poverty and stunting in all districts, but diverse results with respect to natural area loss.

The land use change that occurred in districts with higher trade-offs is more closely related to the conversion of natural area to Cropland and Orchard/Plantations than to Grasslands. Fig. F.1 shows the change from 2005 to 2015 of the three land covers associated with the loss of natural area. For example, the largest increase of Cropland area has occurred in Savannakhet province, where Xaybuly district is located. In contrast, some of the largest increases of Orchard/Plantation Forests occurred in Xaysetha districts in Attapeu province. In the case of Grasslands, however, the largest increase was found in the Houaphan province where there has been low to insignificant socioeconomic progress in the form of falling poverty and stunting.

4. Discussion

4.1 Interactions between nutrition, poverty, and natural area

In this study, we have developed a unique dataset comprising estimates of prevalence of stunting for children under the age of five and have compared these estimates to the prevalence of poverty and spatial coverage of natural area at the district level for Lao PDR in both 2005 and 2015. First, we conclude that poverty and stunting rates are highly heterogeneous across districts in 2005, and even more in 2015. By comparison, the interquartile range (IQR) of stunting rates of countries, gathered by the Oxford Martin School on Our World Data, is as large as the IQR of stunting rates for districts in Lao PDR (Fig. G.3-A). The IQR for poverty rates in Lao PDR is smaller than that which arises across countries, but it still covers 14 percentage points (Fig G.3-B). Also, most districts in Lao PDR retain a rather high coverage of forest area compared to an average country (Fig. G.3-C). When comparing levels of these indicators across districts for each year, we find that the three indicators are significantly correlated. These findings confirm our prior hypotheses. They add further to the emerging evidence that socioeconomic aspects of sustainable developments may be positively correlated – and thus synergetic – but that a trade-off could exist between socioeconomic development on the one hand and environmental impacts on the other (Costanza et al., 2016; Heck et al., 2018; Schmidt-Traub et al., 2017; Singha et al., 2021). In Lao PDR, districts with relatively low stunting and poverty outcomes are predominantly concentrated along major rivers and lowland areas. These areas are associated with high levels of agricultural activity and more generally, greater economic activity (Schönweber et al., 2012). These findings indicate that agricultural land use activities could link the loss of natural

Table 1

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<tbody>
<tr>
<td>Stunting Rate – Poverty Headcount</td>
<td>0.64****</td>
<td>0.58****</td>
<td>–0.14</td>
</tr>
<tr>
<td>Stunting Rate – Natural land per capita (log)</td>
<td>0.75****</td>
<td>0.72****</td>
<td>0.03</td>
</tr>
<tr>
<td>Poverty Headcount – Natural land per capita (log)</td>
<td>0.57****</td>
<td>0.44****</td>
<td>0.08</td>
</tr>
<tr>
<td>Stunting Rate – Agricultural land per capita (log)</td>
<td>–0.16**</td>
<td>–0.24**</td>
<td>0.12</td>
</tr>
<tr>
<td>Poverty Headcount – Agricultural land per capita (log)</td>
<td>0.09</td>
<td>0.09</td>
<td>–0.01</td>
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Statistically significant at: \( p < .0001 \), \( p < .001 \), \( p < .01 \), \( p < .05 \), \( p < .1 \).
area at the district level in Lao PDR with decreases in stunting and poverty.

When we consider changes from 2005 to 2015 the picture for Lao PDR is less clear-cut, however. We find evidence of potential synergies between changes in poverty and stunting, as well as trade-offs between both of these and with changes in natural land cover. Since we observe these synergies and trade-offs in the vast majority of districts, we can interpret them as, alternatively, “Reinforcing” or “Counteracting”,

Figure 2. Correlations between changes in SDG indicators, at the district level in Lao PDR between 2005 and 2015. Note: Fit linear model represented by the blue line only includes districts with statistically significance estimates for poverty/stunting change. Natural Area Loss p.c. (log) refers to the relative change of Natural Area per capita in 2015 with respect to 2005. Representation of the indicators’ 3D graphs can be found in this link. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 3. Examples of trade-offs and synergies between changes in stunting, poverty, and natural area. Note: All examples show a synergy between stunting and poverty (as both decrease), and a trade-off between these developments and the change in natural areas (which decreases in all districts). Yet, districts highlighted with bar graphs are examples of districts that vary widely in their change (low or high loss) in natural area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
following the classification of SDG interactions proposed by the International Council for Science (Nilsson et al., 2016). But we do not see a significant correlation between the magnitudes of these changes. For example, some districts saw poverty increasing, while changes in the other two key indicators were consistent with national averages. These districts were mostly located in the Salavan province. These observations are at odds with our prior hypotheses.

Our evidence thus cautiously suggests that, at least over short periods and at the local level, trade-offs between socioeconomic progress and environmental preservation may not be inevitable. Understanding the local context then becomes essential for anticipating interactions among different targeted SDGs, a consideration that resonates with a broader literature (Biggeri et al., 2019; Fusco et al., 2017; Nilsson et al., 2018). For example, according to the findings from a case study in Mozambique (Smith et al., 2019), a lack of market access, as well as unsustainable resource management, could lead to limited improvements in rural households’ wellbeing derived from agricultural intensification. Another explanation could be the governance regime of agricultural land use activities. More specifically, our findings might be linked to the difference between large-scale land acquisitions (LSLA) and smallholder agriculture in Lao PDR (Nanhthavong et al., 2020).

Expansion of cropland for food production has the potential to improve food security because smallholders often produce crops for local consumption or for direct sale, which can provide direct benefits for the smallholder household (Delzeit et al., 2017; Herrero et al., 2017; Samberg et al., 2016). Compared to this, LSLA in Southeast Asia, often as rubber plantations, are generally known to have negative implications for local food security (Bissonnette & De Koninck, 2017; Müller et al., 2021; Nanhthavong et al., 2021). A recent review of agricultural land use change in Southeast Asia shows that cases of LSLA often have negative impacts on local food security, whereas the development in smallholder agriculture or smaller commercial investments can have both positive and negative impacts depending on the local conditions (Appelt et al., 2022). In the case of Lao PDR, cropland reflects both smallholder agriculture and LSLA, whereas orchards/plantations are predominantly included in LSLA (Ornetsmüller et al., 2018). Indeed, the highest natural area loss in our results is associated with LSLA for the purpose of orchards and plantations (See Fig. F.1). These findings suggest that the development of smallholder agriculture could improve food security, and potentially also reduce poverty, with relatively small losses in natural areas, thus reducing trade-offs between these socioeconomic and environmental indicators. Conversely, the same observations further add to the evidence of the negative impacts of LSLA (Debonne et al., 2021), as these are hardly related to improvements in food security and reductions in poverty, while the detrimental impacts on biodiversity habitat are large. Even so, there were districts in Lao PDR with similar LSLA developments, like for rubber, which did not result in the same environmental impact (See Rubber LSLA in Fig. H.1-C).

The impact of LSLA on household welfare in Lao PDR could also depend on how they were implemented in the region. On one hand, Nanhthavong et al. (2020) report how rubber deals in the northwest provinces of Lao PDR applied the “one plus four” concession-like model, in which small farm holders contribute land (one part) while investors contributed technology, finance, labor, and access to markets (four parts). In this model, farmers did not necessarily work on the land included in LSLA, but if they wanted, they could be hired by the company. Overall, this “one plus four” model resulted in more equitably distributed returns and smallholders acquired better access to productive inputs and markets (Nanhthavong et al., 2020). On the other hand, one possible consequence of LSLA is the potential capture of the greatest monetary benefits by the richer population segments within the community. Even if poverty headcounts and stunting rates fall in some districts, inequality could increase, leading to a potential fall in wellbeing among the poorest population (Smith et al., 2019). Fig. H.1-B suggests that this might be the case in areas like the Sanxay district in Attapeu province. Thus, the interactions between these indicators could potentially be linked to the type of land use practiced locally and their effect on food security and income. This highlights the need for nuance and contextual awareness in the design of agricultural land use policies (Debonne et al., 2018).

Although it is commonly assumed that agriculture is the main link between the loss of natural area and progress in welfare indicators, it is possible that the reliance on natural products for food, income, and energy could also be influential for this type of socio-environmental interaction, especially in a country like Lao PDR (Fedele et al., 2021; Ingalls et al., 2020). From this perspective, it is not so clear how a reduction of forest or natural area, due to agricultural expansion for example, would affect the reduction of poverty and malnutrition. Some might benefit through more access to agricultural products, while others could lose through less access to natural products. If these opposing forces are present to different degrees across districts at Lao PDR, this could further help to explain the lack of correlation among changes in the indicators.

Changes in population are yet a further factor that potentially explains some of our observed results. This process could drive not only changes in poverty and stunting but also an increase in deforestation, especially for low-income countries (Duro et al., 2020). In the case of Lao PDR, Ornetsmüller et al. (2018) show that between 2000 and 2016 a maize boom occurred in the southern part of Xaignabouly Province, on the southern border with Myanmar (Ornetsmüller et al., 2018). One might have expected this phenomenon to lead to higher income and thus lower poverty. However, as presented in Figs. 2 and 3, the southern districts of the Xaignabouly Province experienced a slight increase in poverty with a slight loss of natural area. A large population influx, prompted by the maize boom, might have explained the increase in poverty. As it happens, Fig. H.1-A shows that there was only a slight increase in population for this area, considerably lower than the average population growth across all districts. In Xaignabouly Province, population growth seems not to offer an explanation. Indeed, if we compare the population growth between 2005 and 2015 at the district level with the reduction of poverty and stunting, as well as natural area loss, we find no significant correlation (Fig. H.2). These results thus do not support the oft conjectured impact of population pressure on deforestation for Lao PDR (Angelsten & Kaimowitz, 1999; Leblois et al., 2017; Nguyen Van & Azomahou, 2007).

4.2. Policy implications

Implementing local strategies to achieve the Sustainable Development agenda will be a hard task if there is a lack of knowledge of the status and evolution of targets and indicators at the local level. In Voluntary Local Reviews, new indicators are developed by local actors to monitor SDG implementation (Narang Suri et al., 2021). In a recent study by Ciambra et al. (2023), the authors measure and successfully show how closely the VLR indicators from several cities in Europe resemble the ones created at the regional level by the European Union (Ciambra et al., 2023). Small area estimation could similarly offer a tool to achieve vertical coordination for SDG localization between national, regional and local institutions. For example, our study employs identical concepts and measures of poverty and undernutrition, allowing us to observe and compare the same SDG proxies at the subnational level, as are being tracked at the national level. As we saw above, within Attapeu province in Lao PDR, we found one district with evidence of synergies and one district with evidence of trade-offs between our main indicators, all following the same metrics. National governments can benefit from such knowledge to guide policies, share successful cases and avoid institutional fragmentation (Bilely et al., 2021; OECD, 2020).

In recent decades, policymakers concerned with sustainable development often invoke the potential trade-off between fighting climate change and addressing poverty and malnutrition. At the beginning of the century, Anand and Sen (2000) argued for the employment of a universalist definition of sustainable development, where the interest of
future generations should be considered when working to reduce derivations of the present population (Anand & Sen, 2000). Lao PDR is a country with a large potential for economic development and it is expected that some environmental degradation, due to agricultural expansion and/or intensification, will affect the future stock of natural resources or increase the risk of natural disasters for future generations. By identifying where and how trade-offs between socioeconomic and environmental indicators can be avoided, policymakers will be better placed to pursue sustainable development as envisaged in Anand and Sen (2000). Our study contributes by pinpointing places of interest, but further research within local areas is needed to understand the causal interplay between these indicators. In Lao PDR, for example, a case study can be performed in the Xaybuly district (Savannakhet province), where we found an increase in cropland area to the detriment of natural areas.

4.3. Limitations

Progress in the SDG indicators we examined might depend on several other factors apart from their potential interactions. For example, we showed that poverty and stunting reduction in Lao PDR are negatively correlated to its base-year levels in 2005 (Fig. B.1). This result supports the findings from the literature on local Beta-convergence for poverty (Lopez-Calva et al., 2019; Ravallion, 2012). However, areas with high percentages of natural area in 2005, which also had higher poverty and stunting rates, did not experience a particularly high loss of natural area during our ten-year reference period. Thus, socioeconomic development could have other drivers than agricultural expansion, and the link with losses of natural land might well be indirect at best.

Another important factor not included in this analysis, due to the lack of data at the district level for Lao PDR, is the role of land use intensity. According to the Food and Agriculture Organization, food production and cereal yields in Lao PDR have increased dramatically in comparison to its neighboring countries. This might suggest an increase in agricultural land use intensity in the country (FAOSTAT, 2019; Hepp et al., 2019). Since intensification does not affect the area of natural land cover directly, this might explain the absence of correlation between changes in stunting and poverty, and changes in natural area. Conceição et al. (2016) argue that shifting from agricultural expansion to agricultural intensification could create a virtuous cycle of poverty and hunger reduction while avoiding the depletion of land resources (Conceição et al., 2016). However, agricultural intensification could at the same time impact land quality and have a negative effect on both livelihoods and the environment in the long term (Alaeddin & Quiggin, 2008; Phelps et al., 2013). The latter shows how not only studies using correlation analysis are needed to evaluate synergies and trade-offs in the SDG literature, but also studies using causal analysis, which could help untangle the true determinants of these interactions.

Finally, it is important to point out that the range of indicators used in this study to portray the status and evolution of three SDGs (1, 2, and 15) at the district level in Lao PDR remains limited. Most SDGs have multiple targets and indicators to monitor progress, and the status and changes in one indicator are not necessarily representative of this SDG. For example, Lusseau et al. (2019) argue that poverty reduction affects positively all other SDGs (Lusseau & Mancini, 2019). In Lao PDR’s case, there has been a loss of natural area in all districts, including those that have achieved significant poverty reduction. More broadly, a review of case study evidence has shown trade-offs and synergies between multiple SDGs in Southeast Asia (Appelt et al., 2022). Specifically, this study found some trade-offs and multiple synergies between poverty (SDG1) and Employment (SDG 10), and mixed outcomes for the interaction between poverty (SDG1) and economic equality (SDG 8). Adding additional indicators in this analysis is, however, constrained by data availability at a subnational scale. While it would, under ideal circumstances, be desirable to add further SDG targets and additional indicators to our dataset, only the ones employed here are tractable given the available data sources and estimation methods.

We attempted to predict other types of undernutrition, like child wasting and underweight, which are also measured with anthropometric data. However, the models for stunting were the most suited due to a higher prediction power. As discussed by Fujii (2010), this is usually the case because characteristics captured in the survey, like parents’ education and housing conditions, do not vary in the short run (Fujii, 2010) and the other two anthropometric measures describe a less chronic type of malnutrition than stunting. We also considered using access to basic services as a potential proxy indicator for SDG 1: No Poverty, because this can easily be measured with Census data. However, these types of characteristics appeared to be linearly correlated with predicted household welfare in the statistical models. Households’ access to electricity was used as a predictor of consumption in the poverty models and access to safe sanitation and access to drinking water were used as predictors of height-for-age z-score in the stunting models. Given the close correlation amongst these indicators, we chose to focus on the consumption- and anthropometric-based indicators of welfare in the present analysis.

In general, indicators in this study were selected not only based on data availability at the local level but also on how suitable they are to represent each SDG. The poverty headcount, as well as stunting rates for children younger than five, have been widely used in the literature to represent prevalence of poverty and malnutrition. Natural area is not strictly an indicator in SDG 15, although forest area is (SDG indicator 15.1). We have included a slightly broader range of land cover types in our analysis as we believe these are a better reflection of the state of biodiversity and habitats in Lao PDR - needed to support life on land. Therefore, we believe this study should be replicated, and potentially expanded, in other countries with larger data availability. Also, our study for Lao PDR can be regarded as a case study for what, at a minimum, can be achieved when data are particularly scarce.

5. Conclusions

At the national level, Lao PDR has been able to reduce the poverty headcount and stunting rates for children below the age of five, while there was a decrease of natural area. In this study, we examined for the first time the status and evolution of these indicators in 2005 and 2015 at the district level. We find that changes in stunting and poverty are mostly synergetic, which could be interpreted as “Reinforcing”. Yet, we find that the trends in poverty and stunting are pointing in an opposite direction from what we find with natural cover, which can be interpreted as “Counteracting”. However, we observe a variety of interactions. Notably, we underscore that the socioeconomic consequences of natural area decline seem to depend markedly on the nature of land conversions. Specifically, our results suggest that increases in cropland are associated with larger reductions in poverty and stunting, while the presence of LSLA, as well as larger shares of tree plantations, are associated with a higher prevalence of stunting and poverty. Altogether our findings suggest that synergies between socioeconomic outcomes and trade-offs between socioeconomic and environmental outcomes remain present at a district level in Lao PDR. Yet, policies towards the 2030 UN Agenda, specifically on the goal of food security, could focus on promoting smallholder development and constraining LSLA development to increase synergies and reduce trade-offs. Using small-area estimation methods and combining these with geographic information can add significantly to our understanding of interactions among SDGs.
Writing – review & editing. Sengchanh Kounnouvong: Funding acquisition, Investigation, Resources, Validation, Writing – review & editing. Chris Elbers: Investigation, Supervision, Writing – review & editing. Methodology. Peter F. Lanjouw: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. Jasper van Vliet: Conceptualization, Funding acquisition, Investigation, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data and code files used for the analysis of this study are available at Mendeley Data Repository DOI: 10.17632/4zbp9x9hkc.1, or for the most updated version at https://github.com/dana89/co/SDBGpaperForWD.

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Appendix A

Appendices to this article can be found online at https://doi.org/10.1016/j.worlddev.2024.106564.

References
