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Review

Peru's road to climate action: Are we on the right path? The role of life cycle methods to improve Peruvian national contributions

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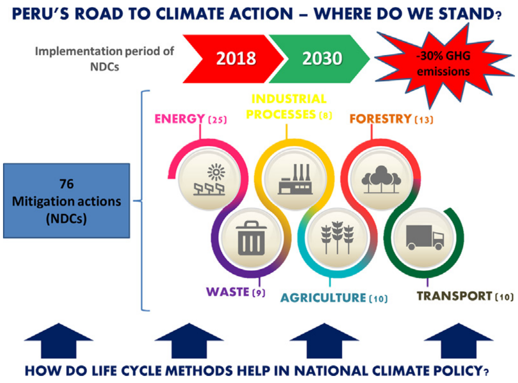
HIGHLIGHTS

- Peru has presented a tentative climate action plan to reduce its GHG emissions.
- It has a baseline scenario target in 2030 to reduce by 30% carbon-related emissions.
- The robustness of each nationally-determined contribution presented is discussed.
- The pertinence of complementing climate policy with life-cycle methods is explored.
- Specific policy recommendations for Peru are established based on the analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

Most developing nations have had to perform a swift transition from the voluntary greenhouse gas (GHG) emissions mitigation actions engaged in the Copenhagen Accord, to the relatively ambitious mitigations signed in the frame of the Paris Agreement. Consequently, Peru is currently creating its national structure to combat climate change through mitigation and adaptation actions. Nationally-determined contributions (NDCs) are the planned interventions that nations report for intended reductions in GHG emissions. In fact, Peru has now committed to reduce its annual GHG emissions by 30% in 2030 with respect to a business-as-usual estimation for that same year. The 76 NDCs have been divided into six main sectors: energy, transport, industrial processes, agriculture, forestry and waste. In this context, the main goal of this study is to provide a critical review of the validity and effectiveness of current mitigation NDCs proposed by the Peruvian government to comply with the Paris Agreement. Moreover, the analysis is accompanied by a discussion on how the use of life-cycle methods, namely Life Cycle Assessment, can be of utility in terms of policy support to evaluate the mitigation potential of these NDCs, as well as in the identification of additional contributions in sectors where the mitigation potential has been obviated. The expansion of system boundaries beyond the national context to account for the globalized nature of current market flows or the modelling of indirect impacts of a particular policy appear as relevant advantages of including life-cycle methods in public climate policy. The analysis, which is intended to be of utility to policy-makers in Peru and in other developing and emerging economies across the world, suggests that life-cycle methods arise as adequate tools to monitor the environmental appropriateness of adopting or adapting low-carbon technology to the local context.

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1. Introduction

When the Lima Call for Climate Action was ratified by the Parties on December 14th 2014 at the Conference of the Parties (COP20), for the first time since the beginning of climate change negotiations the wide majority of Parties, including those that represent the highest proportion of the world's greenhouse gas (GHG) emissions, such as China, Russia or the United States, seconded an unprecedented agreement (Tobin et al., 2018). The Call derived in the establishment of the “Lima-Paris Action Agenda”, with the ambitious objective of harmonizing, integrating and accelerating the engagement of the Parties, as well as all parts of society worldwide, in order to set a new, universal climate change agreement that would substitute the erratic and criticized Kyoto Protocol (McLean and Stone, 2012). Thereafter, countries made efforts throughout 2015 to fix what were named the “intended Nationally Determined Contributions” (iNDCs), a series of individual actions, some of which have been recycled from previous commitments (e.g., Nationally Appropriate Mitigation Actions – NAMAs), destined at creating a set of priority lines in different sectors to mitigate GHG emissions by 2030 (UNFCCC, 2014, 2016). These iNDCs were then ratified in the Paris Agreement in 2016 as the pivotal elements in the new climate governance model (Rajamani, 2016; Tobin et al., 2018), to become what are now referred to as nationally determined contributions (NDCs).

Some criticisms have arisen suggesting that the Paris Agreement lacks the necessary details in many contributions, and that many of these are conditional to a set of external factors, such as funding, capacity building or technological support (Rogelj et al., 2016). Nevertheless, regardless of the current weaknesses of the Paris Agreement, it has introduced a polycentric bottom-up approach to combat climate change (Jordan et al., 2015). This is particularly relevant in terms of how developing countries are reformulating the way in which they must face this global issue. In this sense, developing countries had initiated a path towards mitigation actions using as a starting point the Copenhagen Accord, in which they complied with a series of non-binding voluntary actions to reduce GHG emissions (Bodansky, 2010).

In the specific case of Peru, the mitigation actions specified in the Copenhagen Accord, all intended to be implemented by 2021, were the following: i) zero deforestation; ii) reduction in the GHG emissions linked to waste disposal and treatment; and, iii) targeting one third of total energy in the energy matrix from renewable sources, although it was later extended to 40% (UNFCCC, 2010; Gobierno del Perú, 2015). With only three years to go until 2021, these actions appear to have failed. For instance, the amount of low-carbon energy in the energy matrix has dwindled slightly throughout the 21st century despite the entry of wind and solar energy in the grid (Vázquez-Rowe et al., 2015; MINEM, 2017), the waste management system is still unable to mitigate GHG emissions in most landfills, and the deforested land area has continued at a relatively constant pace of over 150,000 ha/year in the period 2013–2016,[1] still far from the zero target set for 2021 (MINAM, 2017a). The Government admits that part of the failure is due to the lack of stakeholder or sectorial involvement and the absence of an accurate analysis of the technical feasibility of the targets (Gobierno del Perú, 2015).

In contrast, in the new climate policy context fostered through the Paris Agreement, Peru faces a situation in which capacity building and political and social awareness allow setting more ambitious GHG emission mitigation targets through the aforementioned NDCs. In addition, the development of the Peruvian NDCs includes, beyond these mitigation actions, the establishment of adaptation strategies to climate change in critical sectors (e.g., agriculture and fishing) (Gobierno del Perú, 2015).

Despite the Government efforts (i.e., the country-specific NDCs based on NAMAs), several studies highlight that self-declared NDCs by countries lack in many cases transparency and are based on the aggregation of a wide set of individual studies that were either externalized through consultancy or other authorities, with subsequent discrepancies in terms of reference year, metrics, and other methodological choices (Rogelj et al., 2016; Iyer et al., 2017). In the case of Peru, for instance, a set of bottom-up modelling scenarios were used to determine the behavior of GHG emissions in each sector (Gobierno del Perú, 2015). Most of these modelling scenarios were computed through statistical regressions and input-output sectorial studies. Thereafter, these were aggregated with a series of top-down parameters, such as GDP and population growth (Gobierno del Perú, 2015).

NDCs are a relatively new contribution to climate policy, despite the fact that many are built on pre-existing NAMAs. In this context, an issue that remains unexplored is the utility that different environmental management tools may provide in fostering high quality assessments regarding the viability of the proposed mitigation actions. One such tool is Life Cycle Assessment (LCA), an internationally standardized method that aims to track environmental impacts from a supply value chain perspective, identifying improvement actions without burden shifting (Hellweg and Milà i Canals, 2014). In fact, LCA has developed as an important methodology to support environmentally informed decisions at a policy level, especially in sectors such as forestry, solid waste management, wastewater treatment or biofuels (Astrup et al., 2015, 2018; Cherubini and Strømman, 2011; Lorenzo-Toja et al., 2015). In this context, we hypothesize that the use of LCA may shed light on whether multinational value chains (i.e., product life cycles) reduce or

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[1] Deforested area in 2016 added up to 164,662 ha, 5.2% higher than in 2015 and the second highest in the period 2001–2016 (MINAM, 2017a).

augment their emissions through analyzing the integrity of the production processes rather than through individual nationally-determined actions that may eclipse hidden impacts beyond national boundaries (Matthews et al., 2008; Weidema et al., 2018), as well as trade-offs in other environmental categories (e.g., eco-toxicity, eutrophication, acidification…).

The main objective of this article is to provide a critical viewpoint of the current mitigation NDCs proposed by the Peruvian government to comply with the Paris Agreement on climate change. Moreover, the analysis is accompanied by a discussion on how the use of life-cycle methods, in some cases in combination with other management, spatial and economic methodologies, can be of utility in terms of policy support to evaluate and improve the mitigation potential of NDCs, as well as in the identification of additional contributions in sectors were the mitigation potential has been obviated. For this, the 76 NDCs currently collected by the Peruvian government were evaluated from a life-cycle thinking perspective, in order to identify whether the use of LCA improves the intended action pursued with these contributions. The analysis, which is intended to be of utility to policy-makers in Peru and in other developing nations across the world, aims at zooming in to the proposed actions in order to understand their feasibility from an environmental perspective.

The framework of this study is organized as follows. Section 2 presents the current climate policy actions that are being conducted by the Peruvian government. In Section 3, the metrics used by Peruvian authorities to measure GHG emissions are described, with a special focus on the business-as-usual (BAU) projection for 2030. The role of LCA in policy support is analyzed in Section 4, whereas Section 5 delves into how LCA can help foster improved NDCs to mitigate GHG emissions. In Section 6, we discuss the opportunities and shortcomings of Peruvian NDCs, while illustrating the main findings and policy implications of this review.

2. The winding road to 2030: Peruvian national mitigation and adaptation strategies

The proposal of NDCs builds on an international strategy to maintain global warming within 2 °C; although certain models indicate that the current established mitigation compromises may only accomplish a 2.6–3.1 °C range (Rogelj et al., 2016). However, there is evidence to support that if global mean warming is limited to a 1.5 °C increase with respect to the pre-industrial level, the consequences of climate change would be substantially lower in terms of economic costs, climate migrations and the emergence of arid areas worldwide (Park et al., 2017). Therefore, it should be expected that in the following Conferences of the Parties (COPs) efforts will arise to tighten the mitigation expectations to steer the warming threshold to 1.5 °C, especially after the publication of the IPCC 1.5 °C Report in early October 2018 (IPCC, 2018). In fact, the NDCs of the different nations that are gathered in the Paris Agreement constitute their national DNA in terms of GHG emissions mitigation, and allow a clear assessment of how each country expects to meet their national mitigation (and adaptation) objectives (Tobin et al., 2018).

For the particular case of Peru, a series of mitigation and adaptation initiatives have been brought about ever since year 2000, and more intensely in the past decade (Gobierno del Perú, 2015). On the one hand, the NDC proposal created in the scope of the Paris Agreement included information that had been developed through the consolidation of mitigation actions: i) the creation of the national GHG inventories; ii) the establishment of baseline scenarios for climate change mitigation in the period 2012–2014 (i.e., *Planificación ante el Cambio Climático*); or iii) the creation of the first NAMAs (MINAM, 2010; Gobierno del Perú, 2015). On the other hand, a battery of adaptation actions have also been pushed through mainly linked to agriculture, forestry, tropical glaciers and vulnerability analysis (PACC Peru, 2018).

In mid-2015 the Peruvian government opened the proposal of intended contributions to society with the aim of socializing its preparation with stakeholders and citizens. The final NDCs, as well as the adaptation measures, ratified in the Paris Agreement add up to a total of 76[2] individual contributions, divided into six main sectors (see Table 1): energy, transport, industrial processes, agriculture, forestry and silviculture and residues. In addition to these main contributions, the Peruvian Government had fixed 33 additional mitigation options that are yet to be quantified due to lack of specific information on these systems (Gobierno del Perú, 2015). In total, the current objective is to reduce the GHG emissions by 90.4 Mt CO_2eq in 2030 on the basis of one of several types of mitigation targets (see Table 2) that have been developed by different nations based on the common but differentiated responsibility (CBDR) of the parties (Ji and Sha, 2015). In this sense, Peru chose the option to fix its mitigation actions as explicit emissions target based on a BAU scenario, which considers the predicted emissions for Peru by 2030 if no climate action is undertaken. In other words, the 30% reduction target proposed by Peru for 2030 has been established through a two-tier NDC approach that has been applied also by other developing nations. In this sense, 20% of the mitigation constitutes an unconditional mitigation pledge that Peru must comply with by 2030, whereas the remaining 10% is subject to aid from international funding mechanisms (Van Renssen, 2015; Gobierno del Perú, 2015).

Regionalization of climate change mitigation and adaptation is a critical issue in the Peruvian context, bearing in mind that the two opposed phases of El Niño – Southern Oscillation (i.e., El Niño and La Niña) trigger diverging effects in different areas of the nation (Betts et al., 2016; Chen et al., 2017). However, the attendance of regional and municipal authorities to the discussion panels on iNDCs creation was considerably low, with many regions having no representation in these meetings. Paradoxically, on March 16th 2018 the Peruvian Congress passed the new Climate Change Act (CCA), which intends to be the first integral effort towards adapting the nation to a decarbonized society (Gobierno del Perú, 2018). It includes the transposition of the 17 Sustainable Development Goals (SDGs) of the United Nations, and opens the door to imposing regionalized target GHG mitigations actions. The new CCA includes NDCs as the management framework to report mitigation actions together the regional and national strategies that may be developed. Interestingly, Article 16 of the Act specifies the productive sectors in which mitigation actions should be executed (i.e., waste, energy, transport, forestry and agriculture), but also mentions the need to progressively shift towards new consumption patterns, improve energy efficiency or advance in the investment in renewable energy. Moreover, Article 17 emphasized the need to preserve Peruvian forests and avoid deforestation or forest degradation (Gobierno del Perú, 2018).

3. National framework to calculate emissions: is Peru on the right track in terms of estimating its BAU?

The BAU scenario analyzed the behavior of the emissions derived from each sector, based on the modelling of factors or drivers that would affect this behavior. These drivers were agreed upon by different national experts in each sector. These results were then combined with a top-down perspective to aggregate emissions that includes the variation of explanatory variables, such as GDP or population growth. The official GHG emissions reported in the National Inventory of GHG emissions (INGEI, following the Spanish acronym), which follow mainly IPCC 1996 Tier 1 guidelines, were used in the modelling. Moreover, considering that each mitigation action will propagate in such a way that it interacts socially and economically with other sectors, as well as

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[2] It is expected that by early 2019 these NDCs should be a total of 62 actions, with some rearrangements done in the different sectors. However, as of December 18th 2018 this information was yet to be published.

Table 1
List of nationally-determined contributions (NDCs) set by the Peruvian Government to comply with greenhouse gas (GHG) emissions mitigation commitments signed in the Paris Agreement.
(Adapted from Gobierno del Perú, 2015.)

Code	Name	Estimated reductions for 2030 (Mt CO_2eq/year)	% of reductions in sector	% of total reductions
E1	Combination of renewable energy in the electricity grid	2.101	18.15	2.32
E2	Generation distributed with solar panels	0.041	0.35	0.05
E3	Rural electrification with solar panels	0.046	0.40	0.05
E4	Electricity connection with Ecuador	0.886	7.65	0.98
E5	Loss reduction in the national grid	0.598	5.17	0.66
E6	Cogeneration in refineries	0.079	0.68	0.09
E7	Cogeneration in the industrial sector	0.713	6.16	0.79
E8	Cogeneration in hospitals	0.028	0.24	0.03
E9	Solar water heaters for households	0.108	0.93	0.12
E10	Replacement of motors based on longevity	0.049	0.42	0.05
E11	VSD technology for motor optimization	0.187	1.62	0.21
E12	Good practices to optimize heaters	0.116	1.00	0.13
E13	Replacement of heaters based on longevity	0.150	1.30	0.17
E14	Replacement of incandescent light bulbs in households	0.133	1.15	0.15
E15	Replacement of fluorescent light bulbs in households	0.081	0.70	0.09
E16	Replacement of fluorescent light bulbs in shops	0.188	1.62	0.21
E17	Replacement of street lights	0.135	1.17	0.15
E18	Energy efficiency labelling for domestic appliances	0.770	6.65	0.85
E19	Integrated management system for energy in industries and services	2.324	20.08	2.57
E20	Reduction in the use of fossil fuels in Iquitos through the connection to the national grid	0.283	2.44	0.31
E21	Improved cookers in rural areas	1.120	9.68	1.24
E22	Replacement of public fluorescent lighting	0.034	0.29	0.04
E23	Smart grids	0.057	0.49	0.06
E24	Efficiency in new buildings	0.619	5.35	0.68
E25	Energy efficiency in brickworks	0.730	6.31	0.81
Total E		11.576	100%	12.81
T1	Public transport system for Lima – Line 2	0.022	0.65	0.02
T2	Scrappage program for public transport vehicles	0.003	0.09	0.00
T3	Replacement of diesel with LNG for heavy duty vehicles	0.502	14.88	0.56
T4	Vehicular Natural Gas (VNG) for buses: conversion of engines and new units	0.266	7.89	0.29
T5	Vehicular Natural Gas (VNG) for vehicles: conversion of engines and new units	0.269	7.98	0.30
T6	Eco-efficient driving capacity building	0.610	18.08	0.67
T7	Introduction of efficient buses and trucks	0.542	16.07	0.60
T8	Hybrid and electric vehicles (passenger cars)	0.188	5.57	0.21
T9	Introduction of efficient gasoline vehicles	0.758	22.47	0.84
T10	Underground lines in Lima (Lines 2, 3 and 4)	0.213	6.31	0.24
Total T		3.373	100%	3.73
PI1	Substitution of clinker with pozzolan (cement)	0.966	19.10	1.07
PI2	Substitution of clinker with steel slag (cement)	0.327	6.47	0.36
PI3	Substitution of clinker with limestone fillers (cement)	0.756	14.95	0.84
PI4	Substitution of coal with natural gas in cement kilns	0.793	15.68	0.88
PI5	Substitution of coal with natural gas in iron and steel furnaces	0.260	5.14	0.29
PI6	Substitution of clinker with rice husk ash for cement production	1.141	22.56	1.26
PI7	Substitution of coal with biomass in cement kilns	0.545	10.78	0.60
PI8	Substitution of coal with biomass in steel and iron furnaces	0.270	5.34	0.30
Total PI		5.058	100%	5.60
A1	Improvement of the condition of natural pastures in the Peruvian highlands	0.083	1.77	0.09
A2	Recovery of degraded soils with silvopasture in the Amazon basin	0.500	10.67	0.55
A3	Use of improved forage varieties in the Peruvian highlands: clover and rye grass	1.344	28.69	1.49
A4	Conversion of rice cultivation to permanent crops	0.633	13.51	0.70
A5	Capacity building to improve rice yield in the Peruvian coast	0.053	1.13	0.06
A6	Intermittent irrigation system for rice in the Amazon basin	0.211	4.50	0.23
A7	Alfalfa	1.601	34.17	1.77
A8	Fertilizers – capacity building	0.177	3.78	0.20
A9	No tillage	0.077	1.64	0.09
A10	Organic matter	0.006	0.13	0.01
Total A		4.685	100%	5.18
F1	Sustainable forestry management in forestry concessions	6.112	10.09	6.76
F2	Management of permanent production forests for which concessions are yet to be granted	6.046	9.98	6.69
F3	Conditional cash transfers to protect community tropical forests in the Amazon region	5.231	8.64	5.79
F4	Community forestry management	0.691	1.14	0.76
F5	Consolidation of Protected Natural Areas	1.553	2.56	1.72
F6	Institutional strengthening actions for the forestry sector: monitoring, control, surveillance and adequate management of forest land	24.495	40.44	27.11
F7	High-yield forestry	7.686	12.69	8.51
F8	Promotion of reforestation actions on degraded lands, abandoned or uncultivated lands that have conditions for reforestation	2.673	4.41	2.96

Table 1 (*continued*)

Code	Name	Estimated reductions for 2030 (Mt CO_2eq/year)	% of reductions in sector	% of total reductions
F9	Agroforestry system for coffee	0.357	0.59	0.40
F10	Agroforestry system for cocoa	0.533	0.88	0.59
F11	Forestry management of Brazilian nuts	0.114	0.19	0.13
F12	Development of a new forestry management system for Brazilian nuts	2.896	4.78	3.20
F13	Improvement of the management of Protected Natural Areas through personnel and infrastructure	2.187	3.61	2.42
Total F		60.574	100%	67.03
D1	Construction of landfills in large cities with LFG treatment	1.506	38.59	1.67
D2	Construction of landfills in medium cities with LFG treatment	0.289	7.40	0.32
D3	Construction of semi-aerobic landfills	0.442	11.32	0.49
D4	Segregation of organic matter for compost production	0.217	5.56	0.24
D5	Recycling in landfills	0.021	0.54	0.02
D6	Methane treatment in WWTPs	0.067	1.72	0.07
D7	Sludge treatment in WWTPs	0.009	0.23	0.01
D8	Electricity generation in WWTPs	0.005	0.13	0.01
D9	Construction of landfills with LFG treatment and electricity generation	1.347	34.51	1.49
Total D		3.903	100%	4.32
G1	General: others arriving from all sectors	1.200	–	1.33
Total		90.369	–	100%

influence the reduction of emissions in these other sectors; a general equilibrium model was developed. For this, the input-output table for Peru in 2007 was used as the benchmark (Gobierno del Perú, 2015).

The modelling provided by MINAM, however, is full of assumptions and limitations that must be discussed in order to understand the robustness of the BAU scenario. For instance, in terms of GDP growth, modelling was based on the assumption that an average annual growth of 4.3% would be attained in the period 2015–2030. However, when the data from the World Bank and other international agencies is consulted, this average value has not been reached in any year since 2015, and is not projected in the period 2018–2020 (World Bank, 2018). In fact, the average growth rate measured and estimated for the period 2015–2020 is 3.6%. Consistent growth rates above 5% would be needed in the period 2021–2030 to comply with the BAU scenario, a scenario that is highly uncertain. Consequently, it is plausible to consider that the BAU scenario is currently overestimating the emissions that would be attained by 2030 without climate change mitigation interventions, assuming that emissions and economic growth will remain directly proportional in this period.

In terms of population growth, the national annual increase was set at approximately 0.7% for the period 2010–2030, in line with the steady decrease in this rate: from 1.7% in the period 1995–2000 to 1.3% in 2010–2015. However, the increase in population is assumed to be uniform across the nation, despite the fact that according to recent statistics, regions in the Amazon basin (i.e., Amazonas, Loreto, Madre de Dios, San Martín and Ucayali) have population growth rates from 15% to 100% higher than the national average (INEI, 2016a). This information is of importance, considering that local and regional land use changes (LUCs) linked to population growth in this area of Peru, including cattle-grazing, agriculture or informal mining, are bound to engender higher carbon removals due to deforestation than in other areas of the nation (Asner et al., 2014; MINAM, 2017a).

Moreover, the current NDCs proposal does not include macro-shocks to the system, such as financial crises or natural disasters (e.g., earthquakes, flooding, wildfires, etc.). While this could be understandable for very stable developed nations that present a higher resilience to major natural disasters, we consider that for the specific case of Peru this vision is essentially myopic. On the one hand, Latin American nations, which tend to be rather volatile in terms of political and social stability, are currently experiencing an important investment crisis due to the corruption scandals around the former biggest holding company in Latin America, Odebrecht (The Economist, 2017; Vergara, 2018). For instance, it is estimated that Odebrecht has cut Peruvian GDP growth to 2.6% in 2017 (World Bank, 2018). On the other hand, the devastating mudslides that Peru suffered in February–March 2017 were a sad reminder that the nation is still highly vulnerable to semi-cyclical climatological disasters in the frame of the ENSO phenomenon (Vázquez-Rowe et al., 2017a). This natural disaster, which caused numerous human casualties, also devastated the northern coast of the country, with dozens of collapsed bridges, lost roads and damage in populated areas. Regardless of the environmental impacts of millions of metric tons of debris that have ended in riverbeds or directly in the ocean, the GHG emissions linked to the replenishment of the material stocks lost in the event are an important shock in the national system that should be considered in the proposal. In fact, while the effects of ENSO are unpredictable in terms of virulence and occurrence, there is a solid literature that demonstrates the semi-cyclical occurrence of this phenomenon. A similar issue occurs with high magnitude earthquakes. For instance, Alatrista and Gutiérrez (2012) estimated that more than 900,000 t of debris were generated in the city of Pisco alone in the earthquake in 2007. Similarly, a simulation performed by García-Torres et al. (2017) for an earthquake event of magnitude 8.6 M_w in the city of Tacna estimated a total of 89,000 m^3 of debris of concrete alone would be generated. An inefficient reutilization of this lost stock could imply the emission of up to 31,000 t CO_2eq just to recover the lost concrete stock in a city of 150,000 people (García-Torres et al., 2017; Vázquez-Rowe et al., 2019).

Another assumption reported in the BAU scenario is linked to the calculation of surface areas affected by forest fires, which constitute an important source of GHG emissions, including methane and N_2O. The BAU scenario considers that the annual surface area affected by these events would be ca. 13,000 ha, which represents the median value in the period 2001–2013. However, this value does not represent the increasing trend in wildfire alerts that Peru has experienced in recent years (from 28 annual alerts in the period 2004–2009 to 66 alerts on average in the period 2010–2014), in line with observation in other Amazon nations (Aragão et al., 2018). In fact, in 2016 a total of 61,744 ha of forest land were destroyed by forest fires (MINAM, 2017a). Chen et al. (2017) suggested recently that ENSO creates a cascade effect in terms of more virulent forest fires in tropical nations due to intensified drought events. Considering that the intensification of ENSO events in Peru is a plausible scenario within climate change models (Tedeschi and Collins, 2017) it is imperative for forest fire carbon emissions to be extensively reported in mitigation objectives. Similarly, adaptation

Table 2
Description of different forms of mitigation target strategies fixed by nations worldwide in the frame of the Paris Agreement.
(Adapted from UNEP, 2015; Vaidyula and Hood, 2018.)

Forms of mitigation contributions	Description	Observations
Base year target	Report on an absolute reduction from historical base year emissions.	The base year chosen varies, with 1990, 2005 and 2010 being the most common. European Union nations follow this scheme.
Baseline scenario target	The form of emissions reduction relative to a baseline projection	Most countries in Central and South America (including Peru), Africa and South Asia have adopted this strategy.
Trajectory target	These express the trajectory of future GHG emissions, which can include a target for peaking of emissions.	South Africa has expressed that its emissions trajectory range includes a peak between 2020 and 2025, a plateauing of emissions for around a decade and a decline in absolute emissions thereafter.
Intensity target	A commitment to reduce emissions intensity by a specified quantity relative to a historical base year.	China aims at reducing emissions per unit of GDP. Other nations with similar schemes are Uruguay or Singapore.
Fixed-level target	A commitment to reduce or control the increase of emissions to a specified quantity in a target year/period. Fixed-level targets include carbon neutrality targets or phase-out targets, which aim to reach zero net emissions by a specified date; for example, zero net emissions by 2050	Some countries that have presented this scheme are Bhutan, Costa Rica or Sierra Leone.

measures regarding forest fires, currently not specified in the proposal, appear as an important step forward to attain lower surface areas affected by these events.

Although not specified in Peru's NDC proposal, the methane conversion factor (MCF) for wastewater accounted for in the INGEI is 0.8 (INFOCARBONO, 2016). In other words, this implies a substantial overestimation of methane emissions. However, when direct sea, river and lake discharges are considered, which are prevalent in a nation with few wastewater treatment plants (WWTPs) and over 55% of the population living in coastal cities, the MCF will typically range from 0 to 0.2. In fact, considering that Pacific rivers are relatively low in organic load, it is presumable that untreated or pretreated wastewater along the Peruvian coast will reach the ocean with minimal methane emissions (IPCC, 2006).

Other limitations include the accountability of international aviation and shipping routes, which are critical in a periphery nation such as Peru, since travelling, and import and export routes are highly dependent on these two transport modes. In this sense, the BAU scenario considers a triplication of GHG emissions linked to domestic flights from 0.68 Mt CO_2eq in 2010 to 2.29 Mt CO_2eq in 2030. However, considering that an important portion of this increase will be linked to the upcoming boost in foreign tourism, this domestic increase is bound to be triggered by a considerable increase in transoceanic air traffic (MINCETUR, 2018).

Finally, the proposal states that the focus of the emissions is centered in three main gases: methane, nitrous oxide and carbon dioxide. This makes sense, considering that most of the remaining GHGs are hydrofluorocarbons (HFCs) that are regulated in the frame of the Kigali Agreement (Papanastasiou et al., 2018). However, the characterization factors (CFs) that have been used to convert the three gases into CO_2-equivalent correspond to the equivalencies provided in the Second Assessment Report (SAR) of IPCC, rather than using the updated values in the fourth or fifth reports (i.e., AR4 and AR5, respectively). In this sense, it should be mentioned that, for instance, the CF for methane has been progressively increased from 21 kg CO_2eq per kg of methane in SAR to 28 kg/kg in AR5, a 33% augmentation (see Table 3). Considering the importance of methane in the emissions in critical sectors in Peru, such as forestry (i.e., deforestation), agricultural production (e.g., rice) or waste disposal (e.g., open dumpsters and landfilling), an update of these estimations should be performed in order to account for the higher impact of methane emissions.

4. The role of Life Cycle Assessment in policy support

Life Cycle Assessment, an internationally standardized methodology to evaluate the global environmental impacts in international value chains (Hellweg and Milà i Canals, 2014), has been repeatedly applied to different productive sectors in Peru throughout the past decade (Quispe et al., 2017). In a similar line to LCA studies conducted in other areas of the world, the utility of these has been of interest in terms of identifying environmental burdens in a particular process, product or service, tracking the most relevant environmental hotspots (ISO, 2006). Thereafter, this information is used to elaborate environmental improvement strategies without burden shifting (Hellweg and Milà i Canals, 2014). In fact, the latter is a major advantage as compared to other life-cycle indicators based on single (e.g., Carbon Footprint) or compartment-specific (e.g., Water Footprint) indicators. More specifically, the application of LCA has shown to be of particular importance in certain policy-making scenarios, which have allowed public policies to shift towards more environmentally-sustainable strategies. For instance, important examples of this have occurred in the bioenergy sector, in which numerous LCA studies have identified the environmental benefits and drawbacks of transitioning to biofuels (Searchinger et al., 2008; Cherubini and Strømman, 2011; Röder et al., 2015). Other examples in which LCA has supported policy-makers in terms of decision-making include the waste sector (Finnveden and Ekvall, 1998; Wanichpongpan and Gheewala, 2007; Manfredi et al., 2009; Astrup et al., 2015), vehicles and mobility (Bauer et al., 2015) or energy (García-Gusano et al., 2017).

Despite the holistic perspective of LCA studies, which allows the simultaneous computation of multiple environmental impacts (e.g., eutrophication, toxicity, air pollution, resource depletion…) based on the material and energy flows of specific processes or products, it is fair to stress that these integrated approaches have been highly skewed towards the evaluation of GHG emissions (Weidema et al., 2008; Laurent et al., 2012). While this observation can be considered a relative failure of the LCA community, in the sense that additional impact categories have been repeatedly shadowed by the computation of global warming potential impacts, it can be also be seen as an opportunity to strengthen climate change mitigation policies and actions without neglecting the trade-offs that may occur throughout the effect-consequence chain of environmental impact beyond climate change.

In fact, the strength of GHG emissions computation in life-cycle studies resides in the analysis of upstream and downstream processes that are inherent to the production system under evaluation. In fact, LCA can also be implemented from a consumption responsibility perspective, allocating all emissions caused by the production, consumption and end-of-life of a good or service from a final demand approach (Weidema et al., 2018). Under IPCC standards, however, the computation of GHG emissions is confined to a national perspective, ignoring in most cases the transnational nature of current manufacturing and service systems due to globalization (Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008a, 2008b; Weidema et al., 2018). This usually leads to an underestimation of GHG emissions for a particular production system when following IPCC standards (Cellura et al., 2018), which is magnified by the lack of a holistic perspective measuring different GHGs, since CO_2, and in some occasions, CH_4, N_2O and a small bunch of other gases, are the only substances evaluated. Moreover, as stated by Weidema et al. (2018), the national approach to reporting and monitoring GHG emissions disregards the globalized nature of current market flows, omitting the increasing outsourcing of emissions in supply value chains. In this sense, LCA can consistently compute climate change impacts related to the full depth of GHGs that are currently known. This can be done in a way that represents the full temporal and geographical context of the production system under assessment. Interestingly, if needed for reporting or other purposes, the granularity of the method allows partitioning the total environmental impact in terms of time, geography or material and energy flows.

Despite the fact that LCA is a standardized method, its flexibility implies that different modelling approaches persist in terms of its implementation. Stimulatingly, we argue that some of these approaches rather than competing can allow obtaining different responses depending on the scope of the analysis (Weidema et al., 2018). For instance, the main LCA approach in terms of volume of scientific papers generated, attributional LCA (ALCA), represents a steady-state perspective to identify the environmental impacts that occur in a particular production system. This implies that a relatively rigid partitioning of energy and material flows is performed for the sake of providing cleaner production and/or mitigation strategies within a confined system. Despite its utility, it lacks a market perspective, in which marginal or incremental changes in a particular production system may induce domino-effect changes in other markets. These changes may have important environmental consequences. In this context, consequential LCA (CLCA) arises as an important alternative. CLCA allows exploring beyond the system boundary of a particular production system by analyzing how an incremental or marginal change in the physical flows of that system affects the market (Larrea-Gallegos et al., 2019). CLCA reports, therefore, the consequences of a predicted change and may be a useful strategy to evaluate changes in environmental impact due to future decisions. Both ALCA and CLCA are sometime referred to as process-based LCA modelling systems, with a “bottom-up” approach. A different approach, economic input-output LCA (EIOLCA), provides a framework in which it is relatively easy to quantify the environmental impacts through a “top-down” perspective that is based on Leontief's input-output or economic interactions between the sectors that conform the economy of a country or region (Matthews et al., 2015). Usually used as a screening tool, it is also useful for hybrid LCA studies when the granularity of process-based LCA does not reach the entire depth of the inventory.

5. How can Life Cycle Assessment help improve nationally-determined contributions to mitigate GHG emissions?

Based on the previous discussion on the utility of LCA in policy support, we argue that life cycle thinking can be a notorious method to be applied in the climate change policy framework. However, it should be noted that the computation metric of GHG emissions in national inventories presents substantial differences as compared to life-cycle approaches. For instance, national inventories focus on annual emissions, whereas in life-cycle methods the timing of the emissions is in most cases transversal to the lifetime of a product or service. However, limited methodological advance has been made in the frame of dynamic/temporal LCA (Shimako et al., 2018). Similarly, national inventories account exclusively for the direct emissions occurring on sovereign territory. Therefore, if a Peruvian farmer is using mineral fertilizer produced in China as a nutrient source on his land, the Peruvian national inventory would exclude GHG emissions and all other environmental impacts occurring in the production of the fertilizer, which would be allocated to the Chinese inventory. Hence, the Peruvian inventory would only account for those impacts occurring once this product enters Peru. Several studies have criticized this perspective, considering that it can turn into a myopic approach in which environmental trade-offs throughout the supply value chain may be omitted (Peters and Hertwich, 2008a, 2008b; Weidema et al., 2018). In addition, the exclusion of the supply chain when accounting GHG emissions or other pollutants also, implicitly, eliminates the environmental responsibility from the purchasing country despite the clearly related environmental impacts triggered by this international trade. Nevertheless, both parties would ultimately face the environmental consequences (Lin et al., 2014).

Table 3
Characterization factors of the main greenhouse gases (GHGs) relative to CO_2 in the IPCC assessment reports.

Common name	Chemical formula	100-year GWP value		
		SAR	AR4	AR5
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28
Nitrous oxide	N_2O	310	298	265

Having these two critical differences (i.e., temporal and geographical nature of emissions) in mind, it is important to consider metrics that analyze GHG emissions based on the final demand for a particular good or service. In this sense, a series of recent LCA studies have brought light regarding valuable policy-making support initiatives in the national context of Peru (Quispe et al., 2017; Vázquez-Rowe et al., 2015, 2017a, 2017b; Ziegler-Rodriguez et al., 2018). These are discussed in this section in terms of their utility to contribute to the national climate change policy, as well as in terms of their wider contribution to the mitigation of other environmental impacts.

5.1. Energy

The energy sector is the sector with most individual contributions in Peru's commitment, with a total of 25 specific actions. These can be subdivided into three main subgroups: i) new renewable energy infrastructure at a connected or decentralized level; ii) replacement of inefficient machinery and equipment at industrial, commercial and residential levels; and iii) cogeneration in industries and refineries (Gobierno del Perú, 2015). In total, a reduction of approximately 10.2 Mt CO_2eq is targeted in this sector in 2030 as compared to the BAU scenario for that year.

In terms of electricity, an ALCA study by Vázquez-Rowe et al. (2015) demonstrated that despite the fact that GHG emissions in Peru's electricity system have been consistently below 350 g CO_2eq per kWh for the past three decades, the tendency has been incremental, with thermoelectric power accounting for most of the additional demand for energy in the high GDP-growth period (2000–2014). Interestingly, this trend has been reverted in recent years, and is expected to continue for the following decade, partially due to the deceleration of the Peruvian economy, but also thanks to increased investment in renewable energy (MINEM, 2017). For instance, the Agency for Investment in Energy and Mining (OSINERGMIN, following its acronym in Spanish) currently forecasts an additional 2030 MW of new hydropower energy to be installed in the period 2018–2023 (OSINERGMIN, 2017a).

Regarding hydropower electricity generation, Peru has depended on this source of energy throughout the second half of the 20th century. Investment in this sector was timid in the period 2000–2014, which gave way to the development of thermoelectricity as an alternative source. However, current investments in the sector suggest that hydropower could well account for up to two thirds of electricity generation by 2030. A recent ALCA study by Verán-Leigh and Vázquez-Rowe (2019) conducted for three hydropower plants constructed in the past decade in the Andes shows that GHG emissions per kWh generated are below 3 g CO_2eq, in the bottom range for hydroelectricity in the literature (thanks to low biogenic emissions), and substantially lower than other renewables, such as photovoltaic (PV) or wind energy. Nevertheless, it should be noted that future plants are expected to shift from the high energy potential run-of-river plants in the Andes to impoundment plants in the Amazon basin. Flooding of these impoundment plants in dense vegetation areas will most certainly imply high biogenic emissions (including methane) which would neutralize the low-carbon benefits of Andean hydropower generation (Hertwich, 2013; Verán-Leigh and Vázquez-Rowe, 2019). In fact, LCA studies of tropical reservoir hydropower plants available in the literature have reported GHG emissions that range from 75 g CO_2eq/kWh to 600 g CO_2eq/kWh, the latter being substantially higher than the average for the current Peruvian grid (Abril et al., 2005; Demarty and Bastien, 2011; Briones-Hidrovo et al., 2017). Hence, although 2.1 Mt CO_2eq of direct emissions are estimated to be reduced by 2030 (i.e., NDC E1) thanks to a combination of hydropower and other renewables, reductions could be substantially lower than expected if additional hydropower capacity is achieved at high biogenic carbon costs.

Another issue of importance in the hydropower sector is the expected glacial retreat in the Andes (Bradley et al., 2006; Schauwecker et al., 2014), as well as the uncertain effect of intermittent droughts and more extreme ENSO phenomena (Chen et al., 2017), which will force the Peruvian energy sector to introduce climate change adaptation measures (Vázquez-Rowe et al., 2015). In this sense, the cross-border electricity interconnection with Ecuador (i.e., E5), a country with a high hydropower production rate, is not only predicted to contribute to mitigation, but could also pose an attractive adaptation measure to minimize the effects of abrupt local changes in water availability. In this context, CLCA modelling could pose an interesting framework to identify which would be the marginal and/or incremental effects of this important milestone in the interconnection of the Peruvian electricity grid, in order to estimate the domino-effect GHG emission changes of this NDC.

In parallel, considering the outstanding reduction in investment costs for PV and wind energy, these two sources of energy have enormous potential in many areas of Peru. In terms of PV installations, solar farms are growing fast in the southern regions of Tacna and Moquegua, which geographically are a prolongation of the Atacama Desert (Diario Gestión, 2018; MINEM, 2018). An LCA study by Bazán et al. (2018) analyzed decentralized PV electricity in urban environments in Peru. Results suggested that this decentralization could provide succulent reductions in GHG emissions in the hyper-arid Peruvian coast, where hydropower does not cover the full demand, and in the Amazon basin, where the electricity grid is deficiently connected, highly reliant on fossil fuels and its redundancy is poor. This finding is in line with NDC E2, which intends to reduce 0.04 Mt CO_2eq in 2030 through the installation of 74.6 MW of PV panels in selected Peruvian cities. However, estimations by Bazán et al. (2018) suggest that only in the city of Pucallpa, where the current grid is fossil-fuel based, mitigation could rise to 0.5 Mt CO_2eq per year if 18% of rooftop area of the city were to be used for PV panels.

NDC E20, however, is controversial, since it implies the construction of a transmission line from the northern Andes to the city of Iquitos. This project adds to other projects to build a highway and a railway to communicate Iquitos through the northern Peruvian rainforest (OSINERGMIN, 2017b). Iquitos is said to be the biggest city on Earth with no road access, which implies that all goods and passengers have to be transported by air or by waterway. This also applies to the energy system, which is based on burning diesel in the local thermoelectric power plant. According to the Peruvian government, E20 would translate into a reduction in 0.28 Mt CO_2eq in 2030. However, this mitigation focuses on the credits obtained from avoiding the combustion of fossil fuels, but does not account for the GHG emissions engendered due to the direct (i.e., highway) and indirect (e.g., proliferation or intensification of activities) deforestation across the rainforest, regardless of the additional negative impacts on biodiversity (Laurance et al., 2009; Gallice et al., 2019). In this particular context, we argue that life cycle methods present themselves as useful tools to evaluate the trade-offs that can occur in complex natural systems, not only in terms of analyzing the wider picture of conflicting projects or interests, but also from an environmental compartment perspective, screening the feasibility of projects through a multiple evaluation of impact categories (i.e., climate change, biodiversity loss, resource depletion, particulate matter formation, etc.).

5.2. Transport

Transport in Peru in the 21st century is still undeveloped, with the rugged orography playing a key role in rocketing economic expenses per kilometer of constructed road or highway. Given the lack of a railway network, all inland passengers and goods depend on roads for mobility. Furthermore, as of 2015, over 30% of passenger vehicles and buses, as well as over 25% of trucks were circulating in the nation with no emission standards (pre-Euro). Hence, although the number of vehicles per 1000 people in Peru is still low, a greater fraction of its vehicle fleet is highly intensive in air pollutant emissions (CAN, 2015; Verán-Leigh et al., 2019).

Transport emissions are the main source of urban pollution in large Peruvian cities, such as Lima, Arequipa or Trujillo. In fact, some metropolitan areas of Lima have been identified as some of those with worse air quality in Latin America and the Caribbean (LAC) (WHO, 2018). In this context, climate change mitigation schemes should also be seen as important actions to improve air quality in urban environments. In fact, a recent study by Shindell et al. (2018) suggests that over 41,000 human lives would be saved in Lima in the period 2020–2100, linked to respiratory health, if more emphasis were given to near-term GHG emissions. More specifically, accelerated reductions of co-emissions leading to air pollution, namely PM2.5 and ozone, would translate into attractive local health benefits that would be soon visible for local communities, rather than the more complex interpretation of global, long-term improvements (Haines et al., 2009; Shindell et al., 2018).

A total of 10 NDCs have been fixed by MINAM in the transportation sector, with varying targets from improving driving efficiency to the implementation of integrated transport systems in the city of Lima. For the latter, however, an ambitious NDC to reduce 1.27 Mt CO_2eq is proposed linked to the opening of lines 2–4 of the underground (i.e., NDC T10). Unfortunately, the pace at which the design and construction of these lines has evolved in the period 2014–2018 leaves little hope for these to be implemented fully by 2030 (AATE, 2018; El Comercio, 2018), an issue that compromises the air quality and climate change targets for transport, especially considering the expected increase of vehicles per 1000 inhabitants (currently at 175 per 1000 people) in a city that is expected to reach 13 million people by 2030 (SINIA, 2017, 2018).

The holistic nature of LCA allows monitoring, in one single interface, the trade-offs between different environmental impacts, particularly air quality and climate change in an urban context. This framework allows policy-makers to generate new transport and mobility scenarios based on holistic interpretations in which the energy-transportation-air quality-climate change nexus is analyzed (Erickson and Jennings, 2017). Moreover, the ability of LCA-oriented studies to transform environmental impact emissions into damage impacts could be highly useful for those actions that affect urban environments, expanding this nexus to health impacts.

A hot topic in many nations, that has engendered numerous LCA studies in the past decade, is the analysis of the environmental trade-offs that electric vehicles (EVs) will generate in the transport sector (Hawkins et al., 2013; Querini and Benetto, 2014). Although most studies point in the direction of a reduction of GHG emissions, this highly depends on the electricity mix that is supporting this transition (Faria et al., 2013; Hawkins et al., 2013). A study developed by Cárdenas et al. (2017) for the city of Lima compared four different scenarios in the period 2015–2030 in which the amount of private passenger cars and the proportion of EV vehicles varied. Results suggested that the adoption of a high rate of EVs in Lima would be the most beneficial scenario provided that an improved public transportation reduces the amount of passenger car use (see Fig. 1). In fact, an increase in the use of public transport would have a higher impact on GHG emissions mitigation (Cárdenas et al., 2017). However, although the implementation of NDC T8 considers the inclusion of up to 35,000 EVs per year by 2030 in the period 2017–2030 and a reduction of 0.19 Mt CO_2eq by 2030, legislation is yet to be passed to regulate the entry of EVs in Peru (MINAM, 2018).

In a similar line, Peruvian cities lack optimization measures to reduce traffic congestion. For instance, the city of Lima has a high percentage of traffic lights that are not synchronized (Tollefson, 2012), which triggers additional congestion and, therefore, pollution. In this context, the implementation of initiatives such as the green wave or green navigation (GN) systems appear as necessary measures to complement NDC T6, that seeks ambitious mitigations (i.e., 0.61 Mt CO_2eq in 2030) linked to driving efficiency improvements (Amirgholy et al., 2017; Pérez-Prada et al., 2017).

In non-urban environments, NDC T3 focuses on a shift in the fuel used to power trucks (i.e., LNG rather than diesel). A total of 0.5 Mt CO_2eq are expected to be mitigated through this action. However, in addition to fuel shifting, the impact of infrastructure and infrastructure improvements could highly influence fuel consumption. For instance, the impact of untarmacked roads or low speed limits on fuel consumption should also be analyzed. In addition, although GHG emissions linked to deforestation of Amazon forest for road expansion is an impact that is attributable to the forestry sector, its cause is intimately related to the need to extract raw materials (e.g., timber, mining products such as gold, etc.) from low access zones in the Amazon basin (Oliveira et al., 2007). Hence, many road projects throughout this region, legal or illegal, should be expected (Larrea-Gallegos et al., 2017; Gallice et al., 2019). Consequently, it is expected for trucks to be travelling at higher speeds in improved roads, but also deepening their reach in remote areas to access raw materials.

An interesting transnational project that has arisen in recent years is to build a railroad that communicates the Brazilian Atlantic coast with the Peruvian coast to foster exports of raw materials through the Pacific. Initially intended to finalize in the port of Bayóbar on the northern coast, the current route, agreed on by Bolivia and Peru in September 2018, will end at the port of Ilo, on the southern coast (TeleSur TV, 2018). This change implies that the layout of the railway on Peruvian soil will avoid generating LUCs in the Peruvian Amazon basin and, consequently, reduce biogenic carbon emissions substantially. Bolivian authorities claim that the railway could generate 10–50 Mt of cargo per year (TeleSur TV, 2018). However, these projections should be analyzed with care, considering that the Interoceanic Highway in the Peruvian Amazon basin, once inaugurated, presented extremely low average annual daily traffic values (Alberti and Pereyra, 2018). Nevertheless, we hypothesize that railroad expansion would generate lower indirect LUCs on either side as compared to roads given the more limited connection points that are usually present in these networks.

Other rail networks for freighting are yet to be implemented in Peru. Although they have already been considered in the current National Railroad Plan in 2016 (Gobierno del Perú, 2016), they are not included in the current NDCs proposal. Even though orography could hinder this transport mode for cargo flows to and from the Andean highlands, there are important flows of cargo along the Peruvian coast, including minerals and metals that could benefit from this low-carbon transport alternative. In fact, several middle-income nations have suggested green freight measures in their NDCs to shift goods transport from roads to more efficient railways and waterways (Huizenga and Peet, 2017).

5.3. Industrial processes

In the industrial sector, the Peruvian Government has proposed a set of eight mitigation actions, six of them related directly to the cement industry. Specifically, lowering the clinker/cement ratio (e.g., pozzolans, rice husk or blast furnace slag), and the use of more environmentally friendly fuels in the clinkerization process (e.g., natural gas or biomass). These actions combined would imply a total annual reduction of 5.06 million t CO_2eq by 2030, of which the cement-related proposals (i.e., NDCs PI1–PI4 and PI6–PI7) represent almost 90% of total GHG emission reduction (i.e., 4.53 million t CO_2eq) (Gobierno del Perú, 2015). The remaining 10% is attributed to NDC PI5 and PI8, linked to the iron and steel manufacturing industry.

The clinkerization process (excluding related combustion processes) generates 63% of the industrial sector's emissions, according to data reported by INGEI for 2012 (i.e., 3.8 million t CO_2eq) and constitutes around 5% of the country's GDP (MINAM, 2012). Considering that INGEI calculates GHG emissions according to the IPCC reporting methodology, only intrinsic process emissions are considered per sector (IPCC, 2006). Hence, energy processes are excluded from the "Industrial

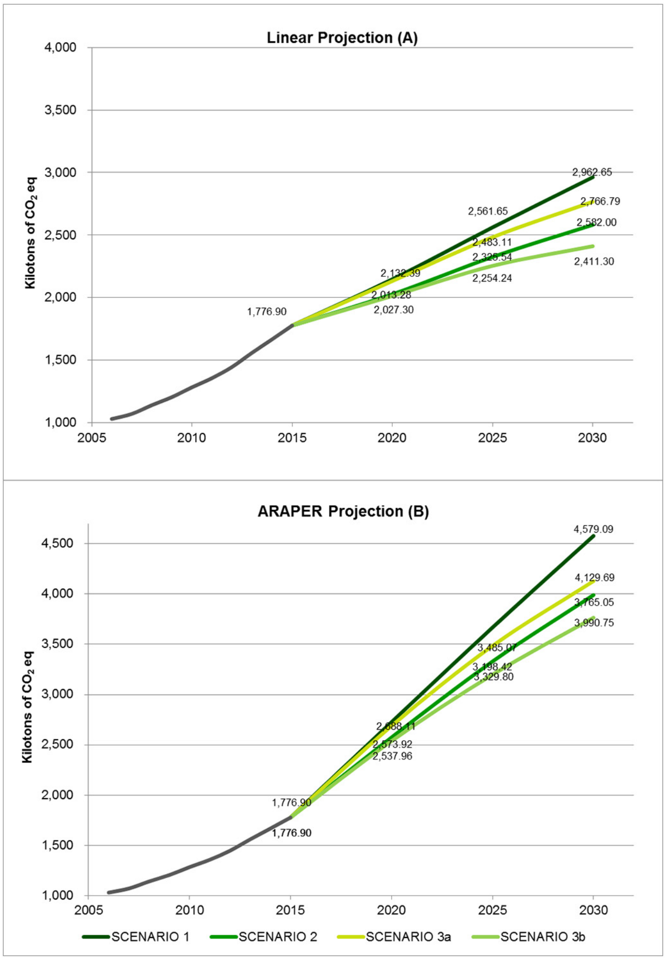

Fig. 1. Total GHG emissions considered for the different mobility scenarios in the city of Lima in the period 2015–2030 based on different levels of public transportation and electric vehicle (EV) penetration in the transport system (adapted from Cárdenas et al., 2017). Projection A considers a linear growth of the number of passenger vehicles in Lima, whereas Projection B is based on projections provided by ARAPER, the Peruvian Automobile Association. Scenario S1 assumes a very low penetration of EVs in the fleet of the Peruvian capital. Scenario S2 foresees a reduction in the current use of vehicles due to an improvement in the public transportation system and a low penetration of EVs. Scenario S3a assumes an adoption rate of EVs similar to other nations in the LAC region, whereas Scenario S3b assumes a higher share of EVs in the new vehicles entering Lima, following the example of countries like Norway.
(Adapted from Cárdenas et al., 2017.)

Processes" segment and are reported as "Stationary Combustion" emissions, in the Energy sector. Due to the lack of specification in the INGEI reports, cement-related combustion emissions were difficult to trace. However, in the Peruvian NDCs report, both combustion and intrinsic cement process emissions are allocated under the industrial processes category (Gobierno del Perú, 2015), making the joint understanding of these two reports more complicated, since the way in which the data are presented could be misleading. This is a clear example of the disadvantages that can emerge when an LCA perspective is not taken into account.

In this sense, an LCA study on the Peruvian cement industry was carried out which assessed conventional and added cement, as well as concrete production (Vázquez-Rowe et al., 2019). The study analyzed and compared the production of conventional (i.e., Portland cement) and added cement in the country's main plants. Results showed that in the case of Portland cement combustion processes and clinkerization accounted for 31% and 64% of total emissions, respectively. Moreover, it was estimated that the substitution of approximately 40% of the clinker with pozzolan would cause a decrease in 33% of GHG emissions. In the same line, the replacement of coal by natural gas in clinker furnaces would imply a decrease in up to 9% of total emissions. However, not all clinker used for cement production in Peru is produced domestically. In fact, imports from countries like South Korea and Japan have been reported throughout the century. Based on recent inventory data for these countries, as well as extended freighting, Vázquez-Rowe et al. (2019), it appears that these options are more energy-intensive. Therefore, although imports reduce the GHG emissions reported domestically, the lack of traceability of NDCs in terms of imports shades the real impacts of the entire supply chain (Weidema et al., 2018).

Even though the NDCs are based on a 2030 production basis according to national BAU projections, these projections assume that cement consumption would be double to that in 2012. In fact, when the Peruvian Contributions were published in 2015, the trend followed an average annual growth rate of 12% in the period 2006–2012 (Asocem, 2018). According to the Cement Producer Association of Peru (ASOCEM), peak cement consumption was reached in 2014, and was of 10.34 Mt of cement – only 10% more than the 2012 production (Asocem, 2018). The situation gets even worse when looking at the 2016 consumption statistics, which show a reduction of 5.6% in the sector. In fact, the major cement producer in the country had an idle capacity of around 50% throughout the period 2016–2018 (Okazaki et al., 2018). Therefore, although the mitigation per unit of cement estimated by national authorities depicts a reasonable mitigation in GHG emissions, the BAU computed considers that by 2030 the Peruvian cement sector would produce 19 million metric tons of cement in 2030 and emit ca. 8.5 Mt CO_2eq per year (Gobierno del Perú, 2015), when the 2017 production rate was 0.2% lower than in 2012 (Asocem, 2018). These values are a clear indicator of the deficiencies and problems that can appear along the calculation and proposal of NDCs, especially for those nations that are not expected to reduce their emissions based on a past historic value, but rather on a projected BAU estimation.

5.4. Agriculture, livestock and fisheries

National contributions only refer to this sector as "agriculture", although it also considers livestock. However, we consider it relevant to extend the analysis to other activities in the primary sector, including fisheries and aquaculture. A total of 4 NDCs have been specified in this sector, adding up to an estimated mitigation of 2.56 Mt CO_2eq in 2030, plus an additional 6 that are subject to international funding, representing an extra reduction of 2.13 Mt CO_2eq (Gobierno del Perú, 2015).

NDCs A1–A2 consider direct emission reductions in pastureland through the conversion of 37,500 ha of pastureland to cultivated pastures that can improve the efficiency of bovine systems. Moreover, A3 aims at reducing by 1.34 Mt CO_2eq in 2030 the emissions due to degraded agroforestry soils. Although studies in the literature have pointed out that Peru has attained an incremental change in its agricultural sector in the past two decades without excessively stressing its rainforest with LUCs (Meyfroidt et al., 2010), this has been attained mainly thanks to exploiting aquifers along the hyper-arid Pacific coast through intensive pumping. In this sense, A4 advocates for a conversion of 54,000 ha of rice production from a flooding system, intensive in methane emissions, to more advanced water management systems. The particular case of rice is of importance considering that this grain has a significant role in the Peruvian diet, with an average annual consumption of approximately 47 kg per capita according to national statistics (ENAPREF, 2012), and representing around 5.3% of the total GHG emissions of average Peruvian diet (Vázquez-Rowe et al., 2017b).

Despite the importance of A4, which is estimated to reduce GHG emissions in 2030 by 0.63 Mt CO_2eq, it is presumed that this value is underestimated due to the use of an obsolete/superseded characterization factor for methane (see Table 3). Moreover, we consider that this measurement does not consider the entire scope of emissions that could be mitigated thanks to improvements in the irrigation system of crops. For instance, two studies conducted in the region of Ica for green asparagus and pomegranate showed that a cultivation site using a High Frequency Intermittent Drip Irrigation System (HFDI System) can minimize water use by approximately 45%, energy for pumping by 45% and fertilization from 10% to 52%, depending on the mineral fertilizer applied (Vázquez-Rowe et al., 2016). Therefore, regardless of direct GHG emission reductions on field thanks to the avoidance of flooding, a reduction in direct on field emissions from fertilizers would be attained (linked to NDC A8), as well as substantial reductions in GHG emissions linked to the energy sector, thanks to the minimization of energy use from pumping. Similarly, minimization of nutrient loss thanks to these efficient fertigation schemes would reduce emissions in the production process of these fertilizers. Finally, the optimization of water at a large scale throughout the hyper-arid Peruvian coast would obviously be a strategic action in terms of minimizing the water stress on coastal aquifers (Schwarz and Mathijs, 2017), provided that the agricultural frontier in these hyper-arid areas does not grow based on these reductions in the current arable land (Larrea-Gallegos et al., 2019). However, despite not being related to the mitigation plans, improvements in water management policies are aligned with the climate change adaptation strategies established by the Peruvian Government (Gobierno del Perú, 2015), a national commitment that can be explicitly shown in the recently ratified Climate Change Framework Act (Gobierno del Perú, 2018).

The Peruvian proposal ignores, in line with IPCC guidelines, the origin of mineral fertilizers. Although the use of organic fertilizers is extended in many areas of Peru, including the use of *guano de isla*, agroexports rely on importing remarkable amounts of mineral fertilizers, all of which are imported from other countries. In this sense, it is important to note that Peru, by importing notable amounts of mineral fertilizers, and exporting agro-products abroad, presents an important deficit in its nutrient balance, an issue that is magnified by the lack of nutrient recovery systems in the wastewater network (Vázquez-Rowe et al., 2017a, 2016). Interestingly, NDC A8 advocates for reducing 0.18 Mt CO_2eq in 2030 through capacity building for farmers regarding the use of nitrogen fertilizers.

Another important issue that is ignored in the NDCs proposal for Peru is the role of agro-exports in environmental impacts, although these should be allotted to the transport sector. More specifically, most of the agricultural production is currently exported through the port of Callao, which implies that trucks transport remarkable volumes of fresh or processed agricultural products along the Panamerican Highway to a central location (i.e., Callao) for export. Hence, we argue that the current policy of strengthening ports in other areas of the Peruvian coast should be considered as a potential NDC in the transport sector, shortening the travelled distance of trucks (MTC, 2018). Airfreighting also has an important role in agro-exports (Girod et al., 2014), since some fresh exports, such as green asparagus, otherwise would not be exported to Europe and other overseas destinations (Vázquez-Rowe et al., 2016). In this case, food technology advances will probably play a key role in elongating the shelf life of these products. In the meantime, the optimization of export routes, which are not always considered in the freighting industry in terms of environmental concerns, should be implemented as transnational actions to mitigate GHG emissions in the food airfreighting industry (Girod et al., 2014).

Finally, is important to note how different socio-economic variables could play a major role in future environmental impact related to agriculture. For example, Larrea-Gallegos et al. (2019) applied a CLCA perspective to the estimated growth of the demand for *pisco*, a grape-based local alcoholic beverage, by 2030. This approach allowed understanding different scenarios of grape for *pisco*-making expansion up to 2030, showing that local on-site GHG emissions could either be mitigated or not depending on fluctuating crop prices throughout the 2016–2030 period. The results also demonstrate the importance of linking market information with environmental impacts, since policy decisions and demand variations can affect market flows beyond the production systems that are being targeted.

Moreover, Peruvian NDCs do not include any specific actions to be taken in the fishing sector in terms of mitigation. To some extent, this is understandable, since it is important to take into account the fact that fisheries worldwide are atomized throughout most nations that have access to the world's oceans. Moreover, GHG emissions in this sector are largely attributable to transport (i.e., fuel use for vessel propulsion) or to postharvest processing, implying that according to IPCC metrics these emissions would be assigned to other sectors (Ziegler et al., 2016). Hence, although fisheries represent less than 2% of the world's GHG emissions, they do not represent an outstanding fraction of a single nation's emissions, except for nations such as Japan, Iceland or Norway (Parker et al., 2018). Nonetheless, the case of Peru is notorious due to the fact that it hosts one of the world's largest fisheries, that of anchoveta (*Engraulis ringens*). In fact, Peru as of 2015 was still the main exporting nation of fishmeal and fish-oil worldwide, although its fraction has been dwindling since the 1980s (Seafish, 2016). Interestingly, this fishery has one of the lowest fuel use intensities (FUIs), defined as the amount of fuel (usually diesel) that is burned in a fishing vessel per metric ton of landed fish, when observing those reported in seafood literature (Parker and Tyedmers, 2015). In fact, according to Fréon et al. (2014) the FUI of the anchoveta fishery in Peru (i.e., 15 kg of diesel per metric ton of landed anchoveta) was found to be ca. 30 times lower than the median FUI of global fishery records since 1990 (Parker and Tyedmers, 2015). Despite the low fuel consumption of the fishery, a study carried out by Avadí et al. (2014) combining LCA with a benchmarking linear programming tool named Data Envelopment Analysis (DEA) suggests that operational benchmarking, including the optimization of routes, would allow reducing 52 kton CO_2eq per year only through reductions in fuel consumption.

The Peruvian fishing industry is dominated by the reduction industry that nourishes the indirect human consumption (IHC) supply chains (e.g., aquaculture). However, recent studies by Christensen et al. (2014) and Cashion et al. (2017) suggest that important economic and social benefits could be attained if the reduction industry is redirected for direct human consumption (DHC). We hypothesize that from an environmental perspective if this policy were to be supported in Peru, GHG emissions would probably be reduced from a supply chain life-cycle perspective (Vázquez-Rowe et al., 2014a), but could go up in a national context if the carbon intensive post-landing activities were to be concentrated in Peru, rather than abroad.

A final note on the Peruvian fishing sector is the fact that fish species are abandoning tropical waters at a pace of 50 km per decade on a global scale (The Guardian, 2016). If this trend were to be confirmed throughout the Peruvian EEZ, climate change adaptation policies would have to be brought forward swiftly. Moreover, from a mitigation perspective, these shifts in species distribution could imply higher fuel combustion efforts to arrive to the fishing grounds.

5.5. Forestry and LULUCs

Peruvian authorities have identified 11 specific actions to apply in the forestry sector to account for land use and land use changes (LULUCs). Considering that LULUCs account for over 60% of Peruvian annual emissions, it should not be surprising that the greater portion of the mitigation effort is put into this sector, with a predicted mitigation of 60.57 Mt CO_2eq in 2030. To contextualize, this amount is equivalent to approximately 130,000 ha of rainforest land in Peru, assuming an aboveground carbon density of 99.3 Mg C/ha and total decay of above- and belowground carbon. Hence, it is a notable effort by Peruvian authorities to mitigate GHG emissions in this sector, in line with the zero deforestation commitment in the Copenhagen Accord (UNFCCC, 2010).

Actions F1–F5 focus on the improvement of the policies and strategies associated with the granting, management and incentives related to permanent production forests, current logging concessions, and protected areas. These measures aim to mitigate 19.63 Mt CO_2eq in 2030 by increasing the profitability of granted concessions, and empowering the management of protected areas (Gobierno del Perú, 2015). In the case of F1 and F2, the actions imply sustainable logging practices that can increase the yield and performance throughout the value chain of logging. In the cases of F3 and F4, the involvement of indigenous communities and civil society in the conservation of forests is proposed. This strategy has shown to have a better effect in decreasing deforestation compared to not implementing any particular governance regime (Schleicher et al., 2017). Regarding F5, which is defined as "consolidation of protected areas", several studies indicate that land allocation (e.g., allocating protected areas) has an important role in reducing deforestation (Miranda et al., 2016; Weisse and Naughton-Treves, 2016; Anderson et al., 2018).

Interestingly, these five actions are highly linked with F6, for which a mitigation of 24.50 Mt CO_2eq is expected. This action focuses on enhancing current Government's authority in terms of land-use management through the control and surveillance of illegal and unplanned activities. However, the proposed approach relies on reinforcing the traditional command and control policy instead of implementing innovative and concrete measures that involve the different actors of deforestation. In this sense, we argue that, in some regions, enforcement practices have not delivered satisfactory results in order to reduce deforestation (e.g., illegal gold mining) (Asner and Tupayachi, 2017; Finer et al., 2018) and a more strategic approach should be implemented. In fact, we consider that the implementation of concrete measures aligned with F6 objectives may encounter two main difficulties: the intricacy of the interaction among deforestation drivers, and the need of improving existing deforestation prediction models.

On the one hand, analyzing the Amazon rainforest dynamism is complex and research focused on understanding the influence between drivers and deforestation has been under development for the past two decades (Hilker et al., 2014). In fact, deforestation is not, in most of the cases, a natural phenomenon, since it is usually driven by different anthropogenic actions that interact among themselves (Kissinger et al., 2012). In fact, determining which activity triggers the chain reaction of deforestation is not a trivial task. Therefore, we suggest that during the land-use management practice, plans and actions should contemplate the main drivers, even if this involves the participation of different governmental actors. This kind of practice, however, may imply performing a trade-off between addressing only the most significant drivers or those in which policy makers have enough competence. Roads, for instance, can sometimes ignite other illegal activities that endanger biodiversity and carbon stocks (e.g., illegal logging or urbanization), even in the cases when the Government has had the competence in terms of planning and construction (Larrea-Gallegos et al., 2017; Gallice et al., 2019). Moreover, roads ultimately facilitate access to once remote areas of the rainforest, now threatened by increased human interventions (Laurance et al., 2009; Barber et al., 2014). Other activities, namely agriculture or mining, depend on factors (i.e., price and demand) that can go beyond legislation. In those cases, it is uncertain to determine whether an action will lead to an expansion or not.

On the other hand, there is a need to implement more sophisticated models that consider the spatial characteristics of the Amazon. The usage of top-down approaches and traditional statistical models for projecting total deforestation is useful and can encompass most of the activities of a country. However, when the potential effects of a specific action in a certain region need to be assessed, a more comprehensive methodology may be required. For instance, the current deforestation BAU scenario assumes that 88% of deforested areas become agriculture, distributed homogeneously throughout the Amazon territory (Gobierno del Perú, 2015; MINAM, 2016). Nevertheless, whenever any specific action is planned (i.e., road building, urbanization), it is necessary to understand which alternative or scenario might generate the highest probability of deforestation according to local variables (e.g., illegal and/or informal mining in the region of Madre de Dios or palm oil cultivation in San Martin) (Asner and Tupayachi, 2017; Bax and Francesconi, 2018). More importantly in a climate mitigation context, this deforestation probability can be converted into a more precise carbon emission value with the usage of recent high-resolution aboveground carbon density maps (Asner et al., 2014). We consider that understanding deforestation patterns, especially those linked to road expansion and planning, are critical to model future LUCs. In this sense, new tools such as machine learning techniques and cloud-based computation can be implemented to evaluate geospatial deforestation through the use of spatially explicit LUC models and high-resolution data (Basse et al., 2014; Mayfield et al., 2017; Holloway and Mengersen, 2018). We consider that this bottom-up approach can complement current top-down models and may become a powerful tool for local decision makers.

Action F7 aims to mitigate 7.68 Mt CO_2eq by means of commercial reforestation activities. Positively, this mitigation proposal is consequent with current private initiatives that aim to implement proper mine closures and implement a proper reforestation program (ref CINCIA). The final set of NDCs actions in the forestry sector is mainly linked to the sustainable management of different agro-forestry or forestry systems, namely coffee – F9 (0.35 Mt CO_2eq), cocoa – F10 (0.53 Mt CO_2eq) and Brazil nuts – F11–12 (3.00 Mt CO_2eq).

However, when analyzing national statistics, it is evident that two worrying trends can be identified. On the one hand, deforestation rates have increased substantially in the 2009–2016 period (i.e., 151,295 ha per year on average) as compared to the period 2001–2008 (i.e., 95,481 ha), an increase of 58% (MINAM, 2016), despite Peru's pledge in the Copenhagen Accord to reach zero deforestation by 2021 (UNFCCC, 2010). In fact, the average amount of deforested area in the period 2009–2016, assuming total decomposition of the carbon stock, is equivalent to higher emissions than those mitigated in 2030 based on the forestry-related NDCs. On the other hand, if forest fires, as abovementioned, continue an increasing trend due to higher exposure of forest land to human interventions or increasingly recurrent droughts (Chen et al., 2017; Staal et al., 2018), the mitigation actions suggested in this sector may be insufficient to consolidate a gain in terms of carbon storage.

In this context, although it is reasonable to state that attributional LCA studies may lack relevance in supporting NDC-related actions in the forestry sector, considering that GHG emissions are mainly dependent on carbon density data, CLCA studies may provide interesting inputs in terms of identifying the environmental impact changes due to marginal and/or incremental changes in the production system under analysis, as demonstrated in previous studies (Finkbeiner, 2014; Vázquez-Rowe et al., 2014b; McManus and Taylor, 2015; Larrea-Gallegos et al., 2019).

5.6. Waste and wastewater management

Solid waste and wastewater management constitute an important challenge for Peru. In this block of actions, Peruvian authorities expect to mitigate up to Mt CO_2eq by 2030. Interestingly, 64% of these reductions are related to actions in landfill facilities, whereas the remaining 36% is linked to wastewater treatment (WWT) processes (Gobierno del Perú, 2015).

Landfilling in Peru, as of 2015, only represented 49.3% of final waste disposition, whereas uncontrolled open dumpsters represent over 40% of total waste disposal (MINAM, 2017b). Regardless of the numerous environmental benefits of landfilling waste rather than dumping, Ziegler-Rodriguez et al. (2019) using an attributional LCA perspective in three landfills in Peru showed that landfilling without any type landfill gas (LFG) treatment translates into a slight increase in GHG emissions mitigation with respect to open dumpsters (see Fig. 2).

Although the national actions proposed are an incremental improvement in the correct direction, with a set of new centralized (5) and decentralized (11) LFG treatment landfills (D1–D2 and D8) and 20 semi-aerobic landfills (D3) spread out throughout the nation, Peru's commitments exclude the transitioning of the entire waste system from open dumpsters to landfills. Furthermore, this limits the application of waste to energy technologies. For instance, of the landfill in the city of Nauta (Amazon basin) was created in 2011 but lacks any type of LFG treatment. Therefore, GHG emissions are up to 4.8% than those linked to dumping these residues. Despite this increase in emissions due to the shift from dumping to controlled landfills without LFG, the evident advantages of MSW disposal in controlled, monitored landfill go beyond climate change mitigation, contributing to reducing other environmental impacts in soil and water (e.g., freshwater eutrophication, eco-toxicity, particulate matter formation, etc.) or reducing littering in natural environments, including the final accumulation of marine litter (Ziegler-Rodriguez et al., 2019). Moreover, in a country highly vulnerable to natural disasters, the consolidation of a landfill-based system should be a priority regardless of the computation of GHG mitigation scores, since this would provide resilience to the nation and, therefore, an adaptation strategy within the context of the Paris Agreement. In fact, the development, beyond the projected landfills specified in the NDC framework, of a robust network of landfills without LFG treatment throughout the nation, would provide Peru with a solid baseline to face post-2030 mitigation actions (i.e., expand LFG treatment or implement waste-to-energy systems), even if these implies a slightly lower mitigation of GHG emissions.

However, when the MSW-oriented NDCs for Peru are analyzed in detail, we also criticize the lack of granularity when it comes to assessing the decay of organic matter. This decay is strongly influenced by local average temperature and by rainfall, with higher carbon storage rates at lower temperatures. This leads to a situation in which in the first 5 years of treatment of 1 metric ton of waste at a landfill located in the Peruvian Amazon basin, over 80–90% of CH_4 and CO_2 emissions have already been released. In contrast, at the landfill in the city of Cusco, where average temperature is below 12 °C, emissions are spaced out through time in a more homogeneous way. The distribution pattern of these emissions is important in terms of their computation in the national framework (see Fig. 3). For instance, 1 metric ton of waste disposed at a landfill or an open dumpster in the Amazon basin in 2025 will have emitted over 80–90% of its emission potential by 2030, whereas this same amount of waste (considering ceteris paribus conditions) in the Andean Highlands would be offsetting above 48% of emissions to the post-2030 period. Therefore, we recommend that Peruvian waste management authorities, beyond focusing on densely populated areas (i.e., major cities), consider implementing an action plan that prioritizes interventions in landfills, as well as the phase out of the more than 1400 existing open dumpsters, in those areas of the nation with highest average temperature (i.e., Amazon basin).

Moreover, waste composition has a strong influence on final results, as has being demonstrated in recent studies (Bisinella et al., 2018). Despite there not being an international standard to characterize waste, SIGERSOL, the Peruvian database for Waste systems, aggregates the waste fractions of hundreds of municipalities across Peru. However, the Peruvian NDC does not only assume that the fraction of organics will remain constant until 2030, but also considers an average aggregated waste fraction for the entire nation, an issue that is bound to translate into high uncertainty in the expected mitigation values, as shown in Fig. 4.

Peru is far behind in the implementation of wastewater treatment plants (WWTPs) throughout its territory. Moreover, most of the existing plants lack the complexity that would be expected, with a recurrent absence of advanced primary and secondary treatment technologies (Vázquez-Rowe et al., 2017a). These technologies, typically used to reduce the nutrient load of wastewater flows, tend to be rather intensive in the use of energy. Hence, it is expected that GHG emissions linked to improved sanitation, a sector that is being enhanced by the current national government, may increase substantially if low-carbon energy sources are not identified to nourish these systems. In contrast, the recovery of energy, nutrients and water from wastewater flows, which technologically are already feasible and applied in many nations (Li et al., 2015), may be an alternative to mitigate GHG emissions in terms of fertilization and energy, as well as reduce the water stress in many areas of the Peruvian coast as a strategy in terms of adaptation (Vázquez-Rowe et al., 2017a).

5.7. Other sectors

The current NDCs proposal for Peru includes a final section for other mitigation options (Gobierno del Perú, 2015). Although this list is not limiting, it currently contains a set of 33 mitigation actions that could be potentially implemented in Peru linked to the six sectors that have been previously analyzed. Current mitigation has been estimated at 1.2 Mt CO_2eq in year 2030 for this group.

A remarkable omission in Peru's proposal, however, is the lack of any reference to mining, which is the main source of revenue for the nation (over 50% of exports in 2016 in terms of economic revenue) (OEC, 2018). A recent publication by Odell et al. (2018) notes that, despite the fact that climate is a critical issue for mining activities; the number of available scientific articles linking mining with climate change mitigation and adaptation strategies is very limited in developing nations. Therefore, although the BAU scenario and some NDCs are linked indirectly to mining through energy and, to a lesser extent, through transport, there are no specific actions included to mitigate GHG emissions in the mineral value chain (Gobierno del Perú, 2015).

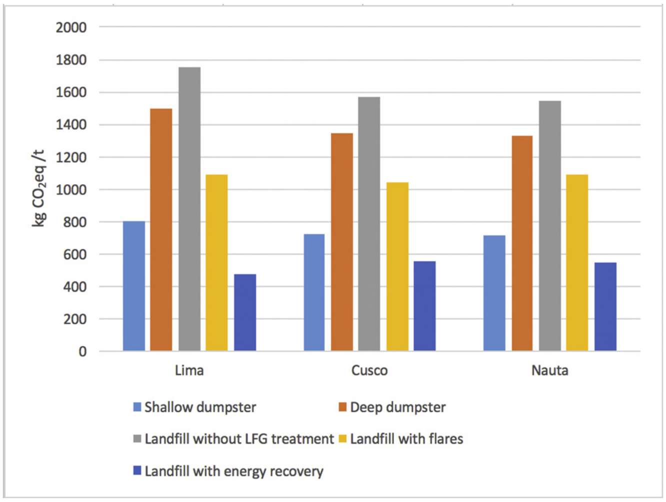

Fig. 2. Comparative LCA results for different municipal solid waste (MSW) management options in different geoclimatic areas in Peru. Results reported for GHG emissions using the Global Warming Potential (GWP) impact category (IPCC, 2013).
Adapted from Ziegler-Rodriguez et al. (2019).

Another important sector that is not directly tackled in Peruvian NDCs is food diets. Although measured to a certain extent transversally in the transport, agriculture and LULUCs sectors, purchase food represents over 40% of household expenditure in Peru (INEI, 2016b). In fact, a study by Vázquez-Rowe et al. (2017b) identified the GHG emissions associated with different dietary patterns in Peru, showing that annual per capita life-cycle GHG emissions attributable to food consumption in Peru ranged from 0.97 to 1.77 t CO_2eq depending on the city under analysis. Although substantially lower than in other nations, these values hide certain malnourishment trends and approximately 5.2 million people exposed to food insecurity (WFP, 2018). Therefore, the estimated growth of the Peruvian middle class is expected to increase food-related GHG emissions due to higher access to meat products, unless effective low-carbon and healthy food awareness campaigns are promoted (Vázquez-Rowe et al., 2017b).

Larrea-Gallegos and Vázquez-Rowe (2018) applied a linear programming optimization model to align Peruvian diets to national diet recommendation guidelines (MINSA, 2012). The results when aggregated to a Peruvian average suggest that up to 250 kg CO_2eq per capita of GHG emissions could be mitigated if these recommendations were followed. In this sense, policy actions aimed at nudging consumers towards low-carbon diets in middle and higher classes (Lusk and McCluskey, 2018); while including environmentally-oriented indicators together with food security when targeting poverty, should be fostered as a way to further mitigate GHG emissions. Although many of the GHG emissions mentioned in the previous lines are not attributable to Peru under IPCC metrics, we argue that dietary policy actions in these lines would help to consolidate more specific actions that are currently specified in the NDC proposal. Similarly, a recent study by Ritchie et al. (2018), analyzed the recommended healthy diets by authorities in different countries, including the US, European nations or India. Their conclusions suggest that most of the national guidelines analyzed are not aligned with the 1.5 °C or 2 °C thresholds, creating important barriers to reach decarbonization targets in 2030 and 2050. Regardless of these drawbacks, LCA arises as a flexible method that allows measuring environmental behavior and assessing potential and means for changing environmental behavior by consumers (Polizzi di Sorrentino et al., 2016).

Tourism is also a sector for which no specific actions have been considered, although some are transversal to the analyzed sectors (e.g., transport, agriculture…). However, it is important to note that tourism is on the rise worldwide and Peru, which received a record 4 million visitors in 2017 (MINCETUR, 2018), has identified international tourism as a critical sector for economic growth despite the carbon-intensive nature of this policy (Lenzen et al., 2018). This policy action

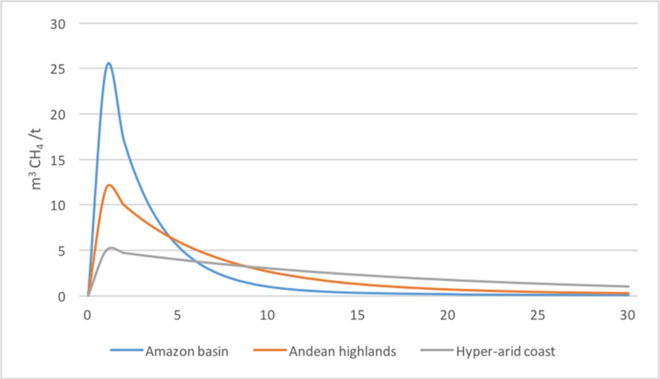

Fig. 3. Temporal evolution of methane (CH_4) and carbon dioxide (CO_2) emissions in an anaerobic landfill under different Peruvian geoclimatic conditions.
Adapted from Ziegler-Rodriguez et al. (2019).

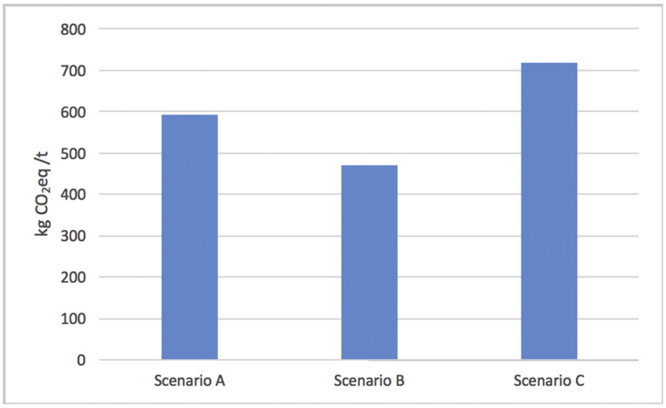

Fig. 4. GHG emissions per metric ton of landfilled waste (with flaring) based on different organic matter content in the waste fraction. Scenario A refers to the current organic matter fraction in a landfill in Lima (52%); Scenario B assumes a hypothetical organic matter fraction of 42%; and, Scenario C assumes a hypothetical organic matter fraction of 62%. The remaining fractions were altered proportionally to these changes in Scenarios B and C. Adapted from Ziegler-Rodriguez et al. (2019).

contrasts with the fact that global demand for tourism is currently going against decarbonization given its increasing reliance on air travel. Interestingly, 15% of tourism-related emissions worldwide are under no binding reduction targets in the frame of the Paris Agreement, i.e., international aviation and marine freighting (Lenzen et al., 2018).

Mining, tourism or food diets are just three additional spheres of the economy for which concrete actions could be carried out that would either complement or redound on many of the NDCs proposed. Complementation is necessary to expand the area of influence throughout the complexity of a countries economy in terms of GHG mitigation, but we also argue that redundancy of actions may allow a higher level of compliment with final target emissions.

Finally, it is important to mention the increasing adoption of Information and Communication Technologies (ICT) in different Peruvian systems (e.g., agriculture through automated weather and irrigation systems or navigation routes for fishermen). While the adoption of ICT in the Peruvian industry is still low, it is probable that, as it rises throughout the sectors, it will lead to an enhancement of efficiency that may lead to substantial GHG emission mitigation (Allenby, 2012). However, special attention will have to be placed on the potential rebound or indirect effects that may be engendered, offsetting the potential of a specific action to reduce GHG emissions (Hellweg and Milà i Canals, 2014). For these complex problems, we hypothesize that CLCA, which currently bears high uncertainty in its results, will become increasingly useful tool in the near future (Plevin et al., 2014). In this context, ICTs will provide accurate dynamic data, which will allow feeding CLCA and other LCA studies with improved data quality. Consequently, the benefits of ICTs in terms of life-cycle studies robustness and certainty may also lead to improved support to policy-makers in the near future.

6. Discussion and conclusions

Peru and many other developing nations are currently transitioning from low public interventions in terms of mitigating GHG emissions to an expected transversal action plan that should lead them to comply with their reported mitigation target in 2030. Beyond the need of aligning all nations in the attainment of the common goal to keep global warming within the 1.5°–2 °C increase threshold (IPCC, 2018), developing nations have an additional challenge linked to attaining competitiveness in a changing world where the energy matrix will no longer be dominated by fossil fuels. Total decarbonization of the economy is starting to become a plausible scenario for certain developed nations (e.g., Denmark, United Kingdom) in their mid-century (i.e., 2050) strategies beyond the NDCs committed in the Paris Agreement (Iyer et al., 2017). Hence, countries which do not adapt to this changing world could see themselves carbon-locked in an era in which renewable energy technology will continue to increase in terms of economic competitiveness (Goldthau, 2017; Ma et al., 2018). Consequently, it is imperative for developing nations, including Peru, to find mechanisms to keep up with these technological leaps (e.g., access to green and smart technology, cultivation of seed investors, an attractive atmosphere for investment…).

Moreover, Peru has been repeatedly identified as one of the countries in the world most vulnerable to the expected effects of climate change (Eckstein et al., 2017; Paun et al., 2018). This should not be surprising, since Peru is already one of the nations that suffer semi-cyclically the effects of ENSO (Ward et al., 2014). Moreover, the highly populated coast is prone to recurrent intense earthquakes that have caused extensive destruction in the recent past (McPhillips et al., 2014), as well as to water scarcity, which is expect to increment as glacial retreat increases (Drenkhan et al., 2015). A fatal combination of these natural disasters could potentially set Peru back in its adaptation to a low-carbon economy, increasing post-2030 challenges. In contrast, Peru, together with other countries in the region, such as Uruguay, Paraguay, Nicaragua or Colombia, forms a group of nations worldwide known as the “Goldemberg's Corner” (Steinberg and Roberts, 2010). These nations are known to have been able to achieve relatively good scores in human wellbeing indicators (e.g., life expectancy, nourishment or improved sanitation), increasing their Human Development Index (HDI) at low ecological costs and at fairly low per capita GHG emissions (i.e., 0–3.5 t CO_2eq) (GFN, 2018). Despite the fact that these indicators hide strong inequalities, Peruvian authorities should use this as an asset in their advantage in these initial stages of decarbonizing the national economy (Loayza and Rigolini, 2016). In addition, there is an open discussion related to the Kuznets curve hypothesis and the environmental implications linked to the need of resources for economic development of a nation. While mitigation of GHGs in the different sectors is the main objective of climate policy (Ma and Cai, 2018, 2019), economic development is a main factor triggering overall GHG emissions in a nation (e.g., Bringezu et al., 2004).

However, it should be noted that the BAU scenario that was modelled to refer mitigation actions is not updated from an economic perspective, since it does not account for the recent deceleration of the Peruvian economy, which is not expected to recover high GDP growth rates until 2020 (World Bank, 2018). The good side of this is that according to a recent study by Robiou du Pont and Meinshausen (2018), Peru would be one of the few American nations to be in track with a 1.5–2 °C increase with respect to pre-industrial levels. However, our concern is that this situation may be seen by authorities as an opportunity to meet the unconditional targets with lower investment costs, since Peru would no longer be on the track of reaching the BAU emissions anyway. On the contrary, we advocate for this deceleration to be managed as an opportunity to work on more ambitious actions that can help reverse the growing technological- and carbon lock-in that Peru has experienced in the past 15 years, in which it has coupled economic expansion and energy demand to the exploitation of domestic natural gas resources (Chavez-Rodriguez et al., 2015; Zambrano-Monserrate et al., 2017). Within this line of thought, we consider that life-cycle methods can aid in the retrieval of adequate technological and decisional pathways to attain these aims.

In this context, life-cycle methods will not provide the needed technology and skills to tackle the decarbonization of the Peruvian economy, but arise as adequate tools to monitor the environmental appropriateness of adopting or adapting low-carbon technology to the local context. In fact, the current development of a life-cycle framework in Peru is enabling the country to obtain more informed decisions in environmental policy (Vázquez-Rowe et al., 2015; Quispe et al., 2017; Larrea-Gallegos et al., 2019). In this line, discussion has arisen in recent years regarding what types of life-cycle studies are more appropriate for policy support in different scenarios (Plevin et al., 2014; Brandão et al., 2014; Dale and Kim, 2014; Weidema et al., 2018). This on-going discussion on the appropriateness of using the different LCA types for the development of policy decisions is mainly linked to the existence of limitations in their modellings that imply, like in any model, that their representation of reality is limited (Brandão et al., 2014). For instance, attributional LCA is not designed to estimate change. Therefore, analyzing how a complex system will react from a climate change perspective to a given "shock" using attributional LCA may lead to misleading results (Plevin et al., 2014). However, if the policy question that should be answered is to evaluate emissions created by specific products or services throughout their supply chain or analyze how policy should be implemented, attributional LCA provides a robust and holistic baseline for GHG emission calculations (Brandão et al., 2014; Hertwich, 2014).

Regardless of the limitations of life-cycle methods, these are destined to provide support in some spheres of science, such as climate change or toxicity, in which uncertainties are inherently high, but decisions must be taken anyway despite lacking or imperfect information (Plevin et al., 2014). This also applies to developing countries like Peru, in which capacity building and skills to build a robust and coherent climate policy framework will have to be developed in parallel to an acceleration of global efforts to mitigate GHG emissions. Beyond Peru's current 2030 target commitments, which have been discussed in depth in the current study, the Paris Agreement establishes a review plan, which should be performed at least every 5 years, so that nations can revise and improve their NDCs. These revision processes will definitely be an opportunity to link a wide range of life cycle-generated information, such as direct support to environmentally informed decisions or steering consumer choices, to mitigation actions in an effort to consolidate Peruvian (and global) climate governance.

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