Environmental costs assessment for improved environmental-economic account for Indonesia

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Submission date: 22-Dec-2022 10:39AM (UTC+0700)
Submission ID: 1985725439
File name: nt_for_improved_environmental-economic_account_for_Indonesia.pdf (1.23M)
Word count: 10111
Character count: 55686

Journal of Cleaner Production 280 (2021) 124521

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

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ARTICLE INFO

Article history:
Received 9 June 2020
Received in revised form
29 September 2020
Accepted 2 October 2020

Handling editor: Bin Chen

Keywords:
Environmental cost
Environmental degradation cost
Ecosystem services
Natural resources depletion

ABSTRACT

The overall purpose of this study is to assess priorities for new environmental accounts in Indonesia. We use environmental costs related to air pollution and resource extraction in Indonesia as a measure for priority. This study uses the damage costs approach to estimate the environmental degradation costs value and the Net Present Value (NPV) approach to obtain the environmental cost of natural resources depletion of several natural resources that are most important for the Indonesian economy. Our estimate of the total environmental costs amounts to around 13% of GDP in 2010. Environmental costs are mostly due to depletion of energy and mineral resources, followed by environmental degradation cost from air pollution, and the use of forestry resources and related depletion of ecosystems. The Indonesian Central Bureau of Statistics (BPS) has already published damage costs data related to resource depletion, which we find is a priority. However, the BPS should consider completing its data with additional information on the depletion costs of ecosystem services related to forestry. Moreover, the BPS could expand Indonesia's economic-environmental accounts by including environmental degradation costs due to air pollution. We found that from a substance perspective, the priorities are SOx, NOx, CO_2, CH_4, and particulate matter. At the same time, from a sector perspective, the priorities are electricity, manufacture of basic iron and steel and of ferro-alloys and first products thereof, mining of coal and lignite, and extraction of peat, because if the national accounts included the external costs of air pollution and the depletion of natural resources, these sectors would create a negative value-added.
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1. Introduction

Achieving the Sustainable Development Goals (SDGs) requires that economic development, particularly in developing countries, ensure that adverse effects of economic activities to the environment are minimized (also compare WCED, 1987 pp.12). For monitoring progress towards SDGs, environmental and economic accounts are needed, but many low-income countries still have problems developing such accounts (Pirmana et al., 2019).

A starting point of proper environmental management concerning economic development is to recognize the cost of environmental impacts due to economic activities and to include them in the decision-making process (World Bank, 1994). Studies have calculated and valued not only the natural resource depletion but also the environmental degradation as a side effect from economic activities (World Bank, 1997; Alisjahbana and Yusuf, 2000a; Bolt et al., 2002; Anielski and Wilson, 2005; Asici, 2013; Obst and Vardon, 2014).

To ensure that the development process proceeds well, Indonesia also needs to develop an accurate and comprehensive environmental-economic account. Indonesia is one of 17 countries with an extraordinary biodiversity (OECD, 2019). Indonesia is well known as the country with the largest area of tropical forests in the world, and it has a very rich coastal and marine ecosystem. The

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https://doi.org/10.1016/j.jclepro.2020.124521
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abundance of natural resources has made Indonesia one of the largest producers and exporters of minerals, energy sources, woods, and agricultural products. At the same time, the country still faces challenges in reducing environmental impacts due to economic activities. Indonesia was the fourth-largest emitter of greenhouse gas in the world in 2015 (Chrysolite et al., 2020), due to emissions from deforestation and peat forest fires, as well as from burning fossil fuels for energy. Other challenges comprise unwise behavior in natural resources extraction, high pollution, and environmental degradation.

In Indonesia, the Central Bureau of Statistics (BPS) has conducted several studies on establishing economic-environmental accounts (including the Green GDP measurement). Those publications are still limited to specific accounts, for instance, forest, energy and mineral accounts. Meanwhile, Indonesia is in the process of expanding its work on environmental accounts, for example, on CO_2 emissions.[1] However, since the collection of new environmental statistics can be costly, it is useful to analyze which kind of environmental accounts are relevant to the respective economic sectors.

Generally, the purpose of this study is to assess the priorities for improving and expanding environmental accounts in Indonesia. We used environmental costs related to emissions and resource extraction in Indonesia as a measure for priority. Based on this background, the present study intends to answer the following research questions: (i) How high are the total environmental costs in Indonesia? (ii) What part of these environmental costs is caused by the environmental degradation cost from air pollution? What sectors and types of air pollutants have the highest environmental degradation cost in the Indonesian economy? (iii) What part of these environmental costs is caused by natural resource depletion from resource extraction sectors in Indonesia? (iv) Which sectors and types of environmental interventions are hence of the highest priority to be covered by environmental accounts?

This paper is broadly structured as follows: Section 2 contains literature reviews on environmental cost accounting methods. Section 3 introduces earlier work on environmental costs accounts for Indonesia and the methodology used throughout this paper. Section 4 presents the results of this study on environmental degradation costs and the costs of natural resource depletion from resource extraction sectors in Indonesia. Section 5 provides a discussion of the findings and the conclusion of the study.

2. Methods for environmental cost calculations

Fig. 1 summarizes the most widely used approaches in environmental cost accounting. Usually, two broad groups of costs are discerned: (a) costs related to environmental degradation caused by emissions (with impacts on the ecosystem and on human health), and (b) costs associated with the use of natural capital and the depletion of natural resources (Alisjahbana and Yusuf, 2004; Jin-nan et al., 2008).

The costs of the first category can be estimated via two main approaches: the damage-based approach and the cost-based approach. The damage-based approach calculates pollution costs due to pollutant discharge, which can cause environmental deterioration (Jin-nan et al., 2008). On the other hand, the cost-based approach calculates the costs required to abate pollutant discharge in the production and consumption processes, the result of which is called maintenance costs.

Cost calculations for the second category usually discern two main types: (1) renewable (biotic) natural resources, such as crops, timber and fish, and (2) non-renewable (abiotic) natural resources, such as metals and non-metal minerals, and fossil energy resources, including water (Hertwich et al., 2010). Renewable natural resources are, in principle, self-regenerating, making use of solar energy. They can be harvested to yield ecosystem goods (such as wood). Non-renewable natural resources cannot be regenerated. Mineral deposits and fossil fuel are the best examples. These resources generally yield no services until extracted. Overexploitation of biotic resources can lead to the collapse of resource stocks (e.g., forests and fisheries) and cause complex environmental problems. Methods for measuring the depreciation/depletion of natural resources can be categorized into three broad groups of approaches: (i) The Market Price Approach, (ii) The Income Approach, and (iii) The Cost Approach.

Environmental cost accounting seeks to monetize the various forms of environmental pressures shown in Fig. 1. Monetization makes it possible to prioritize such pressures and to calculate how environmental costs are related to the Gross Domestic Product (GDP) of a country—for instance, by calculating a “correction” of the GDP. The next section will provide a more detailed discussion of the available methods and approaches for monetizing environmental degradation and natural resource depletion, with an emphasis on the Indonesian context.

2.1. Environmental degradation cost

Environmental degradation is defined as a decrease in the quality of the environment due to development activities. Its value does not include the actual cost of economic activities under the market economy framework (World Bank, 2006; Perman et al., 2011). There is no consensus on the “best” method of valuing environmental damages from economic activities. In practice, several approaches and methods are used to measure environmental degradation costs.

Among others (Jin-nan et al., 2008), pointed out that the environmental costs of pollution can be assessed in two ways, namely by calculating the expenditure on environmental protection and by calculating environmental degradation. The first approach calculates the sum needed to reduce pollutant discharge from production and consumption activities with the Best Technology (treatment) currently available (BAT). The United Nations Economic and Environmental Account System (UN SEEA; see UN, 2003; UN, 2012) defines prevention costs such as ‘maintenance costs’. The second approach is to calculate what damage is caused by pollutant disposal (e.g., for human health, or environmental degradation). UN SEEA refers to these costs as ‘costs of environmental degradation’, or ‘damage value’.

The damage costs approach is more complicated than the maintenance cost approach. However, the damage costs approach provides a better insight into the dangers of pollution for human health and for the environment (Xia et al., 2006).

Table 1 provides an overview of authoritative studies that calculated these damage costs in different contexts. We observed that few studies specifically examine these costs in developing countries. As we will explain further in section 3, we opted for using the studies in Table 1 by adjusting them to an Indonesian context, rather than estimating damage costs via complex emission-effect calculations in the Indonesian situation, for which no data are available.

[1] On November 23, 2016, the Indonesian government signed an MoU with the Dutch Government to collaborate in the context of climate change, waste management, and circular economy as a follow up to the 2015 Paris Agreement to achieve sustainable low carbon conditions in the future.

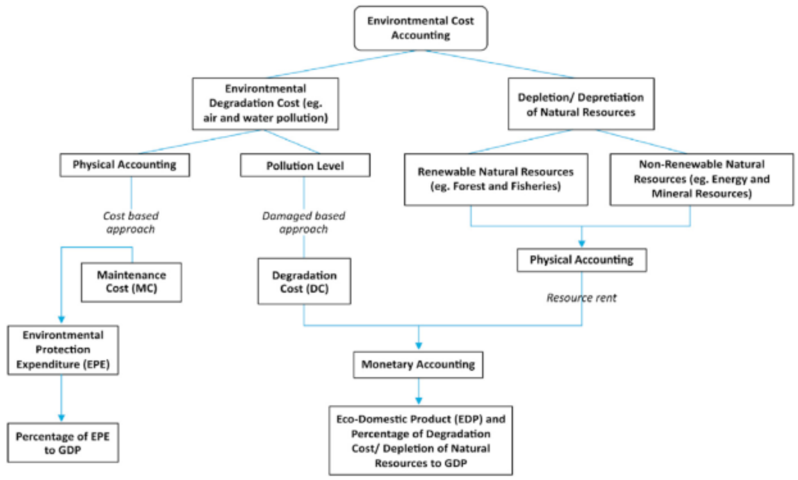

Fig. 1. Approaches to environmental cost accounting Source : Authors, inspired by Alisjahbana and Yusuf (2004); Jin-nan et al., 2008.

Table 1
Publications on Damage/Abatement cost Value for Air Pollution.

	Descriptions	Source/ Institution	Population whose values are considered	Prices	Website	Comments
DAMAGE COST						
1	EPS Impact Assessment Method	Steen (2015)/ Swedish Life Cycle Center	Global	€; /Kg (2015)	https://www.lifecyclecenter.se/publications/eps-2015d1-including-climate-impacts-from-secondary-particles/	Including climate impact from secondary particles
2	EPS Impact Assessment Method	Steen (2015)/ Swedish Life Cycle Center	Global	€; /Kg (2015)	https://www.lifecyclecenter.se/publications/eps-2015d1-excluding-climate-impacts-from-secondary-particles/	Excluding climate impact from secondary particles
3	Environmental Prices Handbook EU28 version	De Bruyn et al. (2018)/CE Delft, Netherlands	28 EU country	€; /Kg (2015)	https://www.cedelft.eu/en/publications/2191/environmental-prices-handbook-eu28-version	Environmental prices were calculated for over 2500 pollutants.
4	Environmental Prices Handbook 2017: Methods and numbers for valuation of environmental impacts	De Bruyn et al. (2018)/CE Delft, Netherlands	Netherlands	€; /Kg (2015)	https://www.ce.nl/en/publications/2113/envionmental-prices-handbook-2017	Environmental prices were calculated for over 2500 pollutants.
5	Eco-costs 2007 LCA data on emissions and materials depletion	Delft University of Technology, 2010	EU countries	€; /Kg (2007)	https://ecocostsvalue.com/EVR/img/Ecocosts%202,007%20LCA%20 data%20on%20 emissions%20 and%20 materials%20 depletion.xls	Eco-costs is a measurement tool that shows the amount of environmental burden of a product based on load prevention €2007/kg emission
6	Costs of air pollution from European industrial facilities 2008–2012	European Environment Agency (2014)	EU countries	€; /Kg (2007)	https://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012/download	This publication is an updated version of the earlier assessment of the costs of air pollution from European industrial facilities (2011)
ABATEMENT COST						
7	Industrial Pollution Projection System (IPPS)	World Bank, n.d	Global	US$/ Ton (1994)	https://datacatalog.worldbank.org/dataset/wps1431-ipps-pollution-intensity-and-abatement-cost/resource/7972b102-9c7b-4146-8df2	Abatement costs value limited to manufacturing sectors only.
8	Pollution Abatement Costs and Expenditures (PACE) Survey	U.S. Bureau of the Census (2008)	USA	Million $ (2005)	https://www.epa.gov/environmental-economics/pollution-abatement-costs-and-expenditures-2005-survey	Abatement costs value limited to manufacturing sectors only.

Source: Authors compilation

2.2. Depletion of natural resources

The theory and literature on environmental costs accounting generally base the valuation of natural resource depletion on market prices. The assumption is that a market price represents a revealed preference and shows how economic decisions are made and can be compared. Several approaches have been used to estimate the depletion of natural resources (Da Motta and Amaral, 2000; United Nations, 2005; Domingo and Lopez Dee, 2007). Domingo and Lopez Dee (2007) categorized these approaches into three categories: (i) the market price approach, (ii) the income approach, and (iii) the cost approach.

2.2.1. The market price approach

Environmental assets are tradable, and their value follows the prices prevailing in the market. Domingo and Lopez Dee (2007) pointed out some advantages and limitations of using the market price approach. Data on quantities, prices, and costs are relatively easy to obtain, especially in established markets. On the other hand, one of several limitations of using this approach is the availability or lack of market data for non-traded resources. Due to policy failures or market imperfections, market transactions may not fully reflect the actual economic value of these goods and services. Moreover, researchers must consider factors affecting prices and seasonal variations. Domingo and Lopez Dee (2007) also pointed out that the market price approach may overstate benefits since this measurement does not subtract the market value of other resources that are necessary to bring ecosystem products to market.

2.2.2. The income approach

An alternative to the market price approach is the income approach, which is an indirect way of using market value or considered a proxy measure of market value where, in reality, a true market does not exist. Four approaches fall into this income approach group: (1) the Net Price Method, (2) the Net Present Value (NPV) method, (3) the El Sherafy/User Cost method, and (4) the Appropriation method. Each approach has advantages and limitations.

Table 2 below presents each approach's advantages and disadvantages for concisely measuring natural resource depletion.

2.2.3. The cost approach

This approach is an alternative measurement for valuing natural resource assets, such as mineral resources. The advantages of this method are reflected in the availability of technical data and specific information on exploration costs (Domingo and Lopez Dee, 2007). On the other hand, the disadvantage of using this method relates to the experience assessments that are needed to distinguish past expenditures that are considered productive from those estimated to make no contribution to the value of the property and to predict what will be reasonable exploration programs and costs in the future.

3. Estimation method for Indonesia

Several attempts have been made to measure environmental costs and to adjust the conventional GDP for the case of Indonesia. These attempts have been initiated since the early 1990s, both by individuals and by local and international institutions. Table 3 below summarizes the most critical studies on environmental cost measurement for the case of Indonesia.

The table shows that in most studies, the measurements of environmental costs only focus on the calculation of natural resource depletion. A few studies attempted to include the calculation of environmental degradation cost caused by emissions, and they usually concentrate on a small number of emissions, such as BOD, CO_2, NO_x, etc. Furthermore, most of these studies are quite dated. There is hence a need to highlight how significant the environmental degradation costs of emissions are in comparison to those of resource extraction. The next section will discuss and elaborate on how environmental costs were estimated in this study.

3.1. Estimation procedures

This sub-section will explain in more detail the methodologies used in the present study for calculating environmental costs for the Indonesian context, divided into the procedures for calculating the costs of (i) environmental degradation due to emissions, (ii) destruction of ecosystems, and (iii) depletion of natural resources.

3.1.1. Environmental degradation due to emissions

Damage costs usually are calculated by estimating damage cost values per unit discharge of a specific pollutant, multiplied by the volume of emission discharge. The formula used to arrive at environmental degradation costs in this study is as follows:

$$ED = \sum_{m}\sum_{n} p_{mn}.uc_n \quad (1)$$

where ED is the environmental degradation costs resulting from the sum of environmental degradation costs by type of pollutant and by sector, p_{mn} is the volume of pollutant m produced per unit output of sector n (pollution intensity), and uc_n is the *unit cost* of pollutants m in sector n (environmental price, Rp/kg).

The environmental degradation cost calculation in this study is limited to air pollution. For calculating the environmental degradation costs related to air emissions and resource extractions by sector, two main data sets are needed:

a) The volume of air pollution emissions by type of air pollutants and by economic sector. Due to the limited availability of data from official sources in Indonesia, this study utilizes emission information from a Global Multi-regional Environmentally Extended Input-Output (GMRIO) database, EXIOBASE, which was developed by a consortium consisting of the Institute of Environmental Sciences (CML), the Netherlands Organisation for Applied Scientific Research (TNO), the Norwegian University of Science and Technology (NTNU) and other partners (Stadler et al., 2018). This consortium estimated emissions by sector for a large number of countries, using, for instance, information of the International Energy Agency (IEA) on fuel use by sector in combination with emission factors. While this information is not official, this source provides a good proxy for emission data by type of air pollutants and by economic sectors. A problem is, however, that EXIOBASE uses a different sector classification than the Indonesian system of national accounts.
b) Several studies/publications are based on environmental prices, primarily obtained from academic institutions and NGOs in Europe (*see* Table 1). Publications or studies on environmental damage costs of emissions in developing countries are absent or very rare. We conducted an extensive analysis of available studies on damage costs of emissions, including emissions of CO_2, Pb, PM10, and CH_4, and we reported our findings in Table 1. We decided to base our present study mainly on damage costs as indicated in the Environmental Prices Handbook EU28 publication version CE Delft, the Netherlands (De Bruyn et al., 2018b). This decision was based on the consideration that in comparison with other publications, the environmental price data published by this institution are up to date and provide the most detailed data based on the type of air pollutants. This data set is also compatible with the classification of types of air pollutants in EXIOBASE. The use of this data set poses various problems, however. For instance, the currency is different, and the data are for a different base year (2015) than the year we used in this study (2010). Finally, there may be a different valuation of the same level of damage in Europe than in Indonesia.

To solve the problems posed by using emission data given in the EXIOBASE classification and by using damage cost data that are sourced for the year 2015 in Europe and calculated in Euro, we used the following approach:

1. Align EXIOBASE and Indonesian data. We first created a

Table 2
Methods based on the income approaches to measure depletion/depreciation of natural resources.

Approach	General description	Advantages	Limitations
Net Price method	The market price minus all factor costs. (UN, 2005)	Simple	(i) This method is built on the assumption of a perfectly competitive market structure; in reality, the premise that rents will increase along with the discount rate may not apply because of market imperfections. (ii) The rent used may also include other forms of rent. (iii) Global mineral prices are not regulated by perfect market mechanisms. (iv) Overestimates the market value of subsoil assets.
Net Present Value	This approach is commonly used to predict the net income stream of an asset over its entire economic life. This includes forecasting future net income streams that can be generated if mineral resources are exploited optimally and then discounting them using appropriate capital costs.	(i) **The time aspect.** This approach recognizes the notion that dollars earned today are worth more than dollars earned ten years from now. (ii) **Risk**. This approach combines the risks associated with resources via the expected income stream and/or the discount rate. (iii) **Flexibility**. NPV provides resilience and intensity because the equation can adjust for inflation and can be used together with other analytic tools.	(i) it is difficult to specify the Income flow, which reflects the estimated Net Benefits during the natural life of the resource. (ii) In this approach, choosing an appropriate discount rate is crucial. (iii) The calculation is done in a static manner, which does not allow for any future adjustments. (iv) The capital requirements may possibly change over time, requiring decisions along the path that may change the risk profile.
El Sherafy/User Cost method	This approach distinguishes between the "actual income" and the "gross revenue" generated by an asset. In this approach, actual income is defined as "the amount of revenue that will be maintained indefinitely regardless of the actual life of the asset by investing a portion of the gross revenue generated which can be a depletion expense or referred to as a user cost".	One of the strengths of this method is that the user cost (1- (X/R)) can be proxied by a formula involving the discount rate and the ratio of annual production to the total stock of resources (1/(1 + r)) n +1)	(i) Several assumptions are needed to calculate the user costs. (ii) During the lifetime of the resource, the current level of receipts is held constant. (iii) Until the final exhaustion of the resource, the rate of extraction is also held constant. (iv) Assumes a constant discount rate.
The Appropriation method	This approach is based on the notion that governments theoretically can collect all rents from resource extraction. The government can collect resource rent through taxes, fees, and royalties imposed on companies that extract the natural resources.		(i) The level of payments to the authority may not move with the market price for the extracted product. (ii) In practice, taxes, royalties, and fees tend to underestimate resource rents because they can be determined by the government.

Source: Summarized from Domingo and Lopez Dee (2007).bib_Domingo_and_Lopez_Dee_2007.

correspondence between EXIOBASE and the sector classification in the Indonesia Input-Output Table (IIOT). In this study, a mapping of the two-sector classification of the dataset was carried out by making a concordance matrix. The EXIOBASE data are categorized into 163 sectors, while the 2010 IIOT distinguishes between 185 industries. By aggregating both EXIOBASE and the IIOT, both were converted into a standard classification of 86 sectors. Furthermore, EXIOBASE itemizes highly specific emission extensions, differentiating, for instance, CO_2 emissions by fuel type and other sources. We aggregated the original 417 emission extensions to 34 substances.

2. Align the base year for environmental prices (damage costs). The volume data of emissions/air pollutants from the EXIOBASE dataset are for 2010, while the available data on environmental prices are based on other years. We therefore re-priced environmental damage costs according to the year and country of origin using the GDP deflator of the OECD National Accounts Statistics.

3. Convert the 2010 environmental prices by type of air pollutant into Indonesian rupiah. The sources we used reported damage costs in Euro and $ per kg emission. For the present study, it was necessary to convert these values into rupiah/kg. We decided to apply a monetary conversion for 2010 based on Purchasing Power Parity (PPP) rather than just using the market exchange rate. For developing countries, the latter would lead to an underestimation of damage costs, since purchasing power is usually higher than an income calculated via the market exchange rate.

4. Multiply the emission volumes estimated under point 1) with the damage costs *per* kg calculated under point 3. The last step to calculate the environmental cost value was to multiply the amount of air pollutant discharge for each sector with the environmental price value for each type of air pollutant.

These conversion steps are shown in detail in an extensive spreadsheet added as Supplementary Information (SI). Table 4 shows the resulting damage costs in Rupiah (Rp)/kg per pollutant for Indonesia for 2010. The total damage costs of emissions by sector in Indonesia are discussed in section 4.

3.1.2. *Value loss of ecosystems*

To estimate the value of ecosystems, or more particularly in this study, of forest resources, we covered two primary sources of destruction: (i) Net depletion of renewable resources (timber resources), often referred to as "excess felling" and defined as the volume of wood produced that exceeds its natural growth. (ii) The loss of ecosystem services from tropical forests due to deforestation.

To compute (i), the net depletion of timber resources, we use the main sources available in Indonesia on physical forest accounts published by the BPS, which cover two types of timber: teak wood and deep forest roundwood.

The stocks (both opening and closing stocks) of timber resources are the stocks of products assessed at a certain period. Additions to the stocks of this type of resources include both plantation and natural growth, whereas the decrease in stocks of these assets covers damages and harvesting or production. We assume that log values destructed by fires constitute a part of destroyed forests.

In constructing the monetary account for timber resources, a unit rent has to be estimated. Data of the physical account is then multiplied by its unit rent to arrive at a monetary account for forest resources.

$$D^R = \sum_j s_j (h_j - g_j) \quad (2)$$

where D^R is depletion/depreciation of renewable natural resources;

Table 3
Summary of previous studies of environmental cost and related adjustments of Indonesia's GDP.

Authors	Coverage	Valuation Methods	Results (Adjustment of GDP,%)
Repetto et al. (1989)	- *Resource depletion:* Oil, soil degradation and forest (including deforestation)	Net price method	17.9 (1984)
Pearce and Atkinson (1993)	- *Resource depletion*: Oil, soil degradation and forest (including deforestation)	Market price	17.9 (1984)
BPS, various years (1996–2011)	- *Resource depletion*: Forest, mineral resources (oil, gas, coal, gold, silver, nickel ore, bauxite)	Net price method	11.7 (1996)
Vincent and Castenada (1997)	*Resource depletion*: several mineral resources, forest, and sub-soil resources.	Hotelling rent	2.5 (1992)
Hamilton (1999)	- *Resource depletion*: oil, gas, broad coverage of minerals, forest; - *Env. degradation*: damage due to emission of CO_2.	Net present Value (NPV) method	14.7 (1994)
Alisjahbana and Yusuf (2000a)	- *Resource depletion:* petroleum, natural gas, several of the most important mineral resources, forest resources - *Env. degradation*: pollution damage from local and global sources	User cost method	5.2 (1995)
Alisjahbana and Yusuf (2000b)	- *Resource depletion:* petroleum, natural gas, several of the most important mineral resources, forest resources *Env. degradation*: pollution damage from local and global sources[2]	Net price method, the maintenance cost approach	10.5 (1997)
Yusuf and Pirmana (2009)	*Resource depletion:* Forest, oil, natural gas, and several of the most important mineral resources *Env. degradation*: pollution damage from local and global sources	Net price method, the maintenance cost approach	4.27 (2007)
Yuniarti, P. Irma (2013)	*Resource depletion:* crude oil, natural gas, forest, several of the most important mineral resources *Env. degradation*: pollution damage from local (NOx) and global sources	Net price method, the maintenance cost approach	4.2 (2007)
BPS, various years (2012–2016)	- *Resource depletion*: forest, crude oil, natural gas, and several of the most important mineral resources - Land cover and land use	Net present Value (NPV) method	6.74 (2016)

[2] s All types of pollutants classified into local sources of pollution except for CO_2 emission.
Source: Author's compilation

Table 4
Damage cost value by type of air pollutant.

No.	Air Pollutants	Environmental prices/kg in ThousandRp, 2010)
1	CO_2	0.12
2	CH_4-Methane	4.33
3	N_2O	36.82
4	SO_x	61.95
5	NO_x	36.82
6	NH_3	43.54
7	CO	0.13
8	Benzo (a) pyrene	13.16
9	Benzo (b) fluoranthene	0.50
10	Benzo (k) fluoranthene	0.50
11	Indeno (1,2,3-cd) pyrene	1.53
12	PCBs-Polychlorinated biphenyls	0.04
13	PCDD_F -polychlorinated dibenzo-p-dioxin and dibenzofuran	70,78*)
14	HCB-Hexachlorobenzene	4.63
15	NMVOC	2.86
16	PM10	66.18
17	PM2.5	96.29
18	TSP	35.56
19	As-Arsenic	2144.73
20	Cd-Cadmium	1465.48
21	Cr-Chromium	1.24
22	Cu-Copper	9.65
23	Hg	85,813.91
24	Ni	213.23
25	Pb	13,353.53
26	Se	87.58
27	Zn	16.57
28	PAH	18.77
29	SF6	3309.15
30	HFC-Hydrofluorocarbons	2650.72
31	PFC-Perfluorocarbons	–
32	Nitrogen	7.74
33	Phosphorus	11.82
34	Emissions n.e.c – Waste	–

Notes: *) in Billion rupiah.
Source: Author's calculation based on various sources of the damage cost values by types of air pollutants, see supporting information. In short, data on damage costs were taken mostly from the Environmental Prices Handbook for the EU28, produced by CE Delft in 2018, and were adjusted to the Indonesian context. For other types of air pollutants, we used values from other sources. The value for CO_2 was taken from the US EP, the value for PCDD_F was taken from EEA publication (EEA, 2014), and the values for TSP, Se and HFC were taken from the Eco-cost 2007 LCA data, the only source providing them. Data for PAH were taken from the EPS Impact Assessment Method dataset of the Swedish Life Cycle Center.

s_j is unit rent of renewable natural resources j; h_j is the quantity of a renewable natural resource j, and g_j is the natural growth of that renewable resource j.

Equation [2] shows how to calculate the depletion or depreciation value of renewable natural resources. Based on this equation, rather than multiplying the unit rent by the number of resources obtained, the authors of this study considered it better to multiply the unit rent by the net depletion or the quantity of the resource obtained (hj) minus its natural growth (gj).

To calculate (ii) the loss of ecosystem service value of tropical forests, we multiplied the area of primary forest cover loss (ha) with the unit values of ecosystem services from tropical forests. Due to the limited availability of data from official sources, we utilized data for primary forest cover loss for 2010 from Margono et al. (2014). The estimated value per ha of ecosystem services from tropical forests was taken from Costanza et al. (2014). Since the unit value data is only available for 1997 and 2011, with values in int.$/ha/year in 2007 constant prices, we converted the data in the following steps: we first converted the unit value $2007/ha/year into unit value $2010/ha/year using the US CPI data. Next, we calculated the loss of value of ecosystem services of tropical forests by multiplying the unit value with the number of ha of forest cover loss. We finally converted the value into Indonesian rupiah using the PPP. The SI shows these calculation steps in detail.

3.1.3. Depletion of natural resources

This study estimated the value of non-renewable resources depletion for the essential mineral and energy resources in the Indonesian economy, i.e., crude oil, natural gas, bauxite, tin, coal, nickel ore, gold, and silver, in terms of monetary accounts, based on a physical accounts dataset from the BPS publication on SISNERLING. After considering and comparing the strengths and limitations of each of the natural resource depletion measurement methods in section 2, we decided to use the NPV approach to assess the costs of resource depletion for non-renewable resources. The use of this approach is also recommended by SEEA-CF 2012 (United Nations, 2014).

The formula used to estimate the depletion/depreciation of non-renewable natural resources in this study is as follows:

$$D^{NR} = \sum_i r_i q_i \quad (3)$$

where *DNR* is depletion/depreciation of non-renewable or exhaustible natural resources; i is the type of non-renewable natural resources; r_i is the unit rent (or value) of non-renewable natural resources type i, and q_i is the extracted quantity of non-renewable natural resources type i.

Data on the extracted quantity of each of these natural resources (qi) was obtained from the publication "Statistics of Oil and Gas Mining" and "Statistics of Non-Oil and Gas Mining" published by the BPS. For each resource, the unit rent (ri) is estimated by subtracting the extraction costs per unit from the price. Again, the SI shows these calculation steps in detail.

4. Findings on environmental cost calculation for Indonesia

4.1. Total environmental costs

The environmental costs estimated in this study consist of two main components, i.e. (1) environmental degradation caused by air pollution; (2) natural resource depletion. Using the approach explained in the earlier sections, we estimated the total environmental costs at Rp. 915,11 trillion, broken down into Rp 348,35 trillion (38.07%) due to environmental degradation by air pollution, Rp 61.43 trillion (6.71%) due to the depletion of renewable resources (split up into Rp. 33.09 trillion for the value of excess felling of wood, and Rp 28.35 trillion for the loss of ecosystem service value) and Rp 505.33 trillion (55.22%) due to non-renewable resource depletion, see Table 5.

Table 5 shows that the principal source of imputed environmental costs in Indonesia were energy and mineral resource depletion, for which the BPS already has good statistics. However, the table and figure also illustrate the major contribution of environmental degradation costs from air pollutants, for which the BPS has less elaborated statistics.

Table 6 shows the top 10 sectors with the highest Total Environmental Cost/Value-Added Ratio in Indonesia in 2010. The table shows that six sectors have total environmental costs that are larger than their value-added (VA): Sea and coastal water transport; Recycling of waste and scrap; Manufacture of basic iron and steel and ferro-alloys and first products thereof & Re-processing of secondary steel into new steel; Mining of coal and lignite, extraction of peat; Extraction of crude petroleum and services related to crude oil extraction, excluding surveying; and Inland water transport. The ratios of environmental cost to value-added across these seven sectors range from 1.53 for sea and coastal water transport to 1.09 for inland water transport. The fact that total environmental costs exceed value-added implies that if the national accounts included the external costs of air pollution and the depletion of natural resources, these sectors would create a negative value-added.

Table 6 also shows that of the ten sectors with the highest ratio of total environmental cost to VA, four are in the extractive sector: extraction of natural gas and services related to natural gas extraction, excluding surveying; extraction of crude oil and services related to crude oil extraction, excluding surveying; mining of coal and lignite; extraction of peat; and mining of precious metal ores and concentrates. The first two of these four sectors occupy the first and second position, with ratios of 24.32 and 11.12, respectively.

Estimating environmental costs allows us to make adjustments to the GDP. Such an adjusted GDP is commonly known as "Eco-Domestic Product" (EDP), where EDP is defined as a GDP that includes elements of degradation of natural resources and the environment (Li and Lang, 2010). Subtracting the value of the environmental costs from Net Domestic Product (NDP) yielded an EDP of Rp. 4678.54 trillion. The environmental costs constituted 16.36% of the Net Domestic Product or 13.33% of the Gross Domestic Product, see Fig. 2.

4.2. Environmental degradation cost by type of air pollutant

As indicated, environmental damage costs due to air emissions are an important part of the total damage costs in Indonesia. In Tables 7 and 8, we present the value of environmental degradation cost by sector and by type of air pollutant. The profile helps to identify the sectors and pollutants with the highest value in environmental degradation costs, which can be considered a priority for inventorying improved data on emissions for the Indonesian situation. Such data also will allow calculating a more accurate Green GDP by, for instance, identifying the priority sectors whose data must be obtained by the BPS or related official institutions, such as the ministry of the environment and forestry.

As was already shown in Table 5, the total environmental costs related to air emissions in 2010 for Indonesia were about 348.35 trillion rupiahs or 5.07% of the total GDP. Table 6 shows the ten sectors with the highest environmental degradation cost value in Indonesia. Based on Table 4, these ten sectors contributed about 73.11% of Indonesia's total environmental degradation costs in 2010. The electricity sector was the sector with the highest costs of

Table 5
Breakdown of environmental costs by type of natural assets (Rp trillion).

Components	Environmental Costs (Rp trillion)	Percentage
1. **Environmental degradation costs (air pollutants)**	**348.35**	**38.07**
2. **Destruction of Ecosystem (forest)**	**61.43**	**6.71**
- Net depletion/excess felling of wood	33.09	3.62
- Loss of eco-services Value of tropical forest	28.35	3.10
3. **Non-renewable resources (Energy and minerals)**	**505.33**	**55.22**
Environmental costs	**915.11**	**100.00**

Source: Author's calculation

Table 6
Top 10 sectors with total environmental cost (tTEC)/value-added (VA) ratio.

No.	Sector	Total Environmental Costs (Rp trillion)	Value-Added (Rp trillion)	TEC/VA
1	Extraction of natural gas and services related to natural gas extraction, exc. surveying	128.49	5.28	24.32
2	Extraction of crude petroleum and services related to crude oil extraction, exc. surveying	196.20	17.64	11.12
3	Electricity	47.86	19.59	2.44
4	Meat animals nec.	2.94	1.62	1.82
5	Manufacturing of basic iron and steel and of ferro-alloys and first products thereof & re-processing of secondary steel into new steel	35.85	24.80	1.45
6	Mining of coal and lignite; extraction of peat	185.10	144.91	1.28
7	Mining of lead, zinc and tin ores & other non-ferrous metal ores and concentrates	5.23	4.39	1.19
8	Inland water transport	7.29	6.99	1.04
9	Sea and coastal water transport	29.00	33.16	0.87
10	Manufacture of cement, lime and plaster	17.85	28.81	0.62
	Other Sectors	**259.30**	**6396.49**	**0.04**
	Total	**915.11**	**6683.68**	**0.14**

Source: Authors calculation

environmental degradation in the economy: about 47.86 trillion rupiah's, or 13.74% of the total value of environmental degradation costs.

The following priorities are the manufacture of basic iron and steel and of ferro-alloys and first products thereof, including re-processing of secondary steel into new steel (10.39%); mining of coal and lignite and extraction of peat (8.33%); Sea and coastal water transport (8.32%); Cultivation of paddy rice (7.38%). The remaining five of the ten highest contributors were accountable for 25.23% of the total environmental degradation costs in Indonesia for 2010.

Looking at pollutants, the ten types of air pollutants with the highest costs of environmental degradation in Indonesia are accountable for 326.41 trillion rupiahs or 93.70% of the total environmental degradation cost value (Table 5). SO_x has the highest environmental degradation cost of about 74.56 trillion rupiahs or 21.40% of the total environmental degradation cost value, followed by NO_x (16.44%), CO_2 (13.60%), andCH_4 (10.41%).

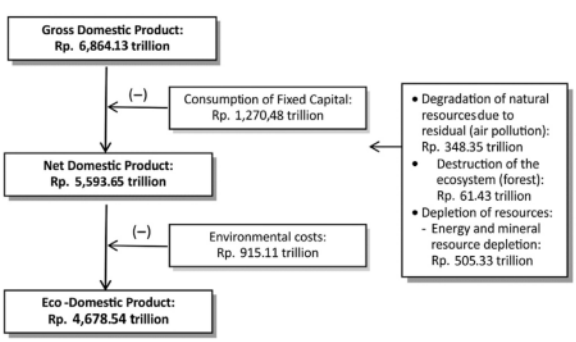

Fig. 2. The 2010 Indonesian eco domestic Product Source : Author's calculations.

Tables 9 and 10 show a matrix of the top 10 sectors and pollutants in terms of environmental degradation cost value. The ten sectors and the ten types of pollutants are the sectors and types of pollutants that must be prioritized, both in terms of data availability, as well as in terms of industrial policy-making in the context of sustainable development. The ten sectors are as follows: Electricity; Sea and coastal water transport; Manufacture of rubber and plastic products; Pulp & Paper; Mining of coal and lignite; Extraction of peat; Manufacture of cement, lime and plaster; Other non-ferrous metal production; Petroleum Refinery; Manufacture of basic iron and steel and of ferro-alloys and first products thereof & Re-processing of secondary steel into new steel; and Chemical. The ten pollutants are SO_X, NO_X, CO_2, CH_4, NH_3, TSP, Pb, PM10, PM2.5, and Nitrogen.

4.3. Loss of ecosystem services from deforestation

The environmental costs of the extraction of forest resources and the related ecosystem depletion consist of excess felling of timber above its natural growth, forests damage and conversions, but also include the loss of eco-services of forests due to economic activities.[3] In Indonesia, many economic activities involve the conversion of forest areas to commercial areas, such as estates and transmigration areas. Also, there is a large amount of forest damage due to both human activities and natural causes. This forest damage and the effects of conversion should not be neglected in estimating the environmental costs since they contribute to the reduction of forest products in the future. Table 11 provides an overview of the estimated results of the net depletion (excess felling) of timber resources. The value of environmental costs is equal to Rp. 61.43 trillion, almost half of which, Rp. 33.09 trillion, is due to net depletion (excess felling) of forest resources, calculated as growth

[3] excess felling also known as depletion of forest resources.

Table 7
Ten highest environmental degradation costs values by sectors.

No	Sector	Environmental Degradation Cost (Rp trillion)	Percentage
1	Electricity	47.86	13.74
2	Manufacture of basic iron and steel and ferro-alloys and first products thereof & Re-processing of secondary steel into new steel	35.85	10.29
3	Mining of coal and lignite; extraction of peat	29.02	8.33
4	Sea and coastal water transport	29	8.32
5	Cultivation of paddy rice	25.72	7.38
6	Manufacture of rubber and plastic products	24.49	7.03
7	Livestock and their results	18.43	5.29
8	Manufacture of cement, lime, and plaster	17.85	5.12
9	Fertilizer	13.75	3.95
10	Construction	12.7	3.65
	Other sectors	93.69	26.89
	Total	348.35	100%

Source: Author's calculation

Table 8
Ten air pollutants with the highest environmental degradation costs values.

No	Pollutants	Environmental Degradation Costs (Rp trillion)	Percentage
1	SO_X	74.56	21.40
2	NO_X	57.27	16.44
3	CO_2	47.39	13.60
4	CH_4	36.28	10.41
5	NH_3	30.50	8.75
6	TSP	20.69	5.94
7	Pb	18.03	5.18
8	PM10	17.01	4.88
9	PM2.5	14.86	4.27
10	Nitrogen	9.83	2.82
	Other pollutants	**21.94**	**6.30**
	Total	**348.35**	**100%**

Source: Author's calculation

minus felling, conversion, and damages. Meanwhile, the value of destruction of the ecosystem due to the loss of eco-services of tropical forests amounted to Rp. 28.35 trillion (calculation details provided in supplementary information).

Most of the destruction resulted from forest fires, either caused by humans or by nature. Human-caused forest damage is the result of shifting cultivation practices, logging damage, or land clearing. Some of the forest fires were exacerbated by nature (wind, dry temperature, etc.). In this case, it was not possible to obtain a more detailed account of forest damage due to each of these causes.

4.4. Depletion of natural resources

This study covers the depletion of non-renewable resources such as minerals and energy carriers. Table 12 shows the depletion value from energy and mineral resources: the depletion value from oil resources amounts to Rp. 190.40 trillion, the depletion value from natural gas is about Rp. 125.84 trillion, and coal depletion is equal to Rp. 156.09 trillion. Moreover, the depletion value from bauxite is equal to Rp. 1.36 trillion, followed by tin (Rp.5,01 trillion), gold (Rp. 25.30 trillion), silver (about Rp. 0.07 trillion), and nickel ore (Rp. 0.36 trillion). Environmental costs due to the depletion of energy and mineral resources in 2010 amounted to Rp 505.33 trillion. The largest contributors to the high value of environmental costs from the depletion of energy and mineral resources are oil,

Table 9
Matrix of the top 10 sectors and pollutants contributing to environmental degradation costs in Indonesia (Rp trillion).

No.	Sectors/Pollutants	SOx	NOx	CO_2	CH_4	NH_3	TSP	Pb	PM10	PM2.5	Nitrogen	Total*)
1	Electricity	21,119	5,874	11,458	46	6	4,135	251	2,948	1,579	-	**47,416**
2	Manufacture of basic iron and steel and of ferro-alloys and first products thereof & Re-processing of secondary steel into new steel	3,132	1,447	416	4	1	7,455	16,806	2,781	2,461	-	**34,503**
3	Mining of coal and lignite; extraction of peat	6,583	1,605	3,096	11,398	0	2,896	116	2,247	869	-	**28,810**
4	Sea and coastal water transport	8,343	8,352	1,749	6	15	667	11	1,209	1,662	-	**22,014**
5	Cultivation of paddy rice	5	102	14	16,849	5,628	6	-	11	15	2,491	**25,120**
6	Manufacture of rubber and plastic products	8,333	4,135	7,247	57	17	1,872	342	1,429	817	-	**24,250**
7	Livestock and their results	43	2,742	113	3,952	9,458	50	0	89	122	344	**16,914**
8	Manufacture of cement, lime and plaster	4,741	2,970	3,666	1	1	1,743	127	2,276	2,258	-	**17,783**
9	Fertilizer	527	3,919	201	4	2,423	21	1	38	47	2,108	**9,289**
10	Construction	126	5,934	4,602	18	178	1	53	590	724	-	**12,229**
	Other sectors	**21,604**	**20,186**	**14,828**	**3,943**	**12,770**	**1,844**	**328**	**3,389**	**4,304**	**4,886**	**88,082**
	Total *	**74,556**	**57,266**	**47,391**	**36,278**	**30,496**	**20,693**	**18,034**	**17,007**	**14,859**	**9,830**	**326,409**

Source: Author's calculation
Notes:
*) Total value of top 10 sectors

Colour	Range
	>10,000
	3,000-9,999
	346-2,999
	<346

Table 10
Matrix of the top 10 sectors and pollutants contributing to environmental degradation costs in Indonesia (%)*.

	Sectors/Pollutants	SOx	NOx	CO2	CH4	NH3	TSP	Pb	PM10	PM2.5	Nitrogen	Total
1	Electricity	6.06	1.69	3.29	0.01	0.00	1.19	0.07	0.85	0.45	-	13.61
2	Manufacture of basic iron and steel and of ferro-alloys and first products thereof & Re-processing of secondary steel into new steel	0.90	0.42	0.12	0.00	0.00	2.14	4.82	0.80	0.71	-	9.90
3	Mining of coal and lignite; extraction of peat	1.89	0.46	0.89	3.27	0.00	0.83	0.03	0.64	0.25	-	8.27
4	Sea and coastal water transport	2.39	2.40	0.50	0.00	0.00	0.19	0.00	0.35	0.48	-	6.32
5	Cultivation of paddy rice	0.00	0.03	0.00	4.84	1.62	0.00	-	0.00	0.00	0.71	7.21
6	Manufacture of rubber and plastic products	2.39	1.19	2.08	0.02	0.00	0.54	0.10	0.41	0.23	-	6.96
7	Livestock and their results	0.01	0.79	0.03	1.13	2.72	0.01	0.00	0.03	0.04	0.10	4.86
8	Manufacture of cement, lime and plaster	1.36	0.85	1.05	0.00	0.00	0.50	0.04	0.65	0.65	-	5.10
9	Unspecified activities	0.15	1.13	0.06	0.00	0.70	0.01	0.00	0.01	0.01	0.61	2.67
10	Construction	0.04	1.70	1.32	0.01	0.05	0.00	0.02	0.17	0.21	-	3.51
	Other sector	6.20	5.79	4.26	1.13	3.67	0.53	0.09	0.97	1.24	1.40	**25.29**
	Total	15.20	10.64	9.35	9.28	5.09	5.41	5.08	3.91	3.03	1.42	**68.42**

Source: Author's calculation
Notes:
*) Percentage value to total emission in the economy
**) Total of top 10 sectors

Colour	Range
	>4%
	1%-3.9%
	< 1%
	<0.09%

Table 11
Environmental cost from the depletion of forest resources, 2010.

1. Net depletion (excess felling)			
Description	Teak wood	Deep forest roundwood on Java	Deep forest roundwood outside Java
Growth (000 M3)*	4779.74	16,669.30	26,957.10
Conversion and Damages (000 M3)	440.80	385.30	248,573.60
Felling ((000 M3)	450.03	439.40	53,550.90
Excess felling ((000 M3)	−3888.91	−15,844.60	275,167.40
Unit rent Rp/cubic meter	190,137.50	13,381.80	120,237.70
Excess felling in (Rp trillion)	−0.74	−0.21	33.09
2. Loss of Eco-services Value			
Unit value $2010/ha/year			5568.45
Forest cover loss (ha)			560,000.00
Loss of eco-services Value from the tropical forest ($ million)			3118.33
Loss of eco-services Value from the tropical forest (Rp trilion)			28.35
Environmental Cost from depletion of Forest Resources (1 + 2) (Rp trilion)			61.43

Notes: *) Thousand cubic meters.
Source: Author's calculation

natural gas, and coal, which together contribute around 93% (see Table 12).

5. Conclusions

This paper reports on an initial effort to assess environmental costs for the purpose of priority setting and as an instrument for assimilating the most relevant environmental aspects into a framework of sustainable socio-economic development. Moreover, compared to other studies on environmental costs in Indonesia, our research provides the most detailed coverage of emissions type data for each economic sector. This study will be beneficial in supplementing Indonesia's existing Environmental-Economic Accounts, as official publications of the BPS Indonesia are still limited to measuring depreciation of natural resources, without including measurements of environmental costs due to environmental degradation.

In order to answer the research questions, two main conclusions

Table 12
Depletion of energy and mineral resources, 2010.

Energy and Mineral Resources	Depletion (Rp trillion)	Percentage (%)
Oil	190.40	37.68
Natural Gas	125.84	24.9
Coal	156.09	30.89
Bauxite	1.36	0.27
Tin	5.01	0.99
Gold	25.30	5.01
Silver	0.97	0.19
Nickel Ore	0.36	0.07
Total	505.33	100%

Source: Author's calculation

can be drawn from our analysis of the environmental costs in Indonesia. Firstly, the environmental costs of environmental degradation, destruction of the ecosystem, and depletion of natural resources in Indonesia for 2010 amounted to Rp. 915.11 trillion, constituting 16.36% of the Net Domestic Product (NDP) or 13,33% of the conventional Gross Domestic Product (GDP). These results do not differ much from the results found in earlier studies, see Table 3.

Second, the environmental cost calculation indicates that natural resources are essential in the context of Indonesia's sustainable development. The environmental cost structure shows that the largest contributor to Indonesia's total environmental cost value is the depletion of natural resources from non-renewable resources (mineral and energy resources), which constitutes around 55.22% of the total environmental costs. The second contributor to Indonesia's environmental costs, amounting to 38.07%, is the cost of environmental degradation, which in this study was only from air pollution. In third place, the destruction of the ecosystem contributes to 6.71% of Indonesia's total value of environmental cost.

Based on the calculation results, it can be concluded that the BPS is on the right track by prioritizing the compilation and publication of the economic-environmental account, which includes regular energy, mineral, and forest resources accounts. However, the BPS publication on the forest resources account is still limited to timber resources. The BPS should consider a complete compilation and publication of this forest account, besides including the costs of loss of ecosystem services.

Third, we found that the value of environmental cost due to air pollution also constitutes a significant contribution to the total environmental costs value, as it is the second largest contributor to the total environmental costs value after non-renewable resources depletion. The cost of environmental degradation from air pollution alone, excluding water and waste pollution, amounts to Rp. 348.35 trillion or 38.07% of the total value of environmental costs, and to around 6.23% of the total NDP.

The BPS has not yet compiled and published a comprehensive economic-environmental account that includes the environmental costs due to environmental degradation. If the BPS plans to expand the scope of Indonesia's economic-environmental accounts by including data on environmental degradation costs due to air pollution, we recommend to prioritize at least the top ten sectors and polluters in terms of the amount of environmental degradation costs they generate in Indonesia. The ten sectors contributing the most to the costs of environmental degradation related to air pollution in Indonesia accounted for around 73.11%. These ten sectors comprise electricity; manufacture of basic iron and steel and of ferro-alloys and first products thereof & re-processing of secondary steel into new steel; mining of coal, lignite, and extraction of peat; sea and coastal water transport; cultivation of paddy rice; manufacture of rubber and plastic products; livestock and their result; manufacture of cement, lime, and plaster; fertilizer and construction. The ten most prominent air pollutants that together generate 93.70% of the cost of environmental degradation from air pollution are SOX, NOX, CO2, CH4, NH3, TSP, PB, PM10, PM2.5 and Nitrogen.

This study's results can be used as a guide for policymakers in formulating environmentally sound economic development policies. However, there certainly is a need for a follow-up study aiming to overcome the limitations and weaknesses of this study, including those of the methods used in this study, but yet able to keep the technique simple, which is especially important for developing countries like Indonesia.

CRediT authorship contribution statement

Viktor Pirmana: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing. **Armida Salsiah Alisjahbana:** Supervision, Conceptualization, Methodology, Writing - review & editing. **Arief Anshory Yusuf:** Validation, Writing - review & editing. **Rutger Hoekstra:** Supervision, Writing - review & editing, Validation. **Arnold Tukker:** Supervision, Conceptualization, Methodology, Validation, Writing - review & editing.

Declaration of competing interest

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

Acknowledgments

This research was funded by the Lembaga Pengelola Dana Pendidikan (LPDP), grant number PRJ-1461/LPDP.3/2016, Ministry of Finance, Indonesia. It is part of the first author's PhD scholarship at the Institute of Environmental Sciences (CML), Faculty of Science, Leiden University, Netherlands.

Appendix A

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.124521.

References

Alisjahbana, A., Yusuf, A.A., 2000a. Trial Estimates of the 1990 and 1995 System of Integrated Environmental and Economic Accounting. the United Nations University/Institute for Advanced Studies, Tokyo.

Alisjahbana, A., Yusuf, A.A., 2000b. Indonesia's Genuine Savings Rates: 1980 – 1997. the United Nations University/Institute for Advanced Studies, Tokyo.

Alisjahbana, A., Yusuf, A.A., 2004. Green Accounting and Sustainable Development in Indonesia. UNPAD Press.

Anielski, M., Wilson, S., 2005. Counting Canada's Natural Capital: Assessing the Real Value of Canada's Ecosystem Services. Prepared by the Pembina Institute for the Canadian Boreal Initiative.

Asici, A. Atil, 2013. Economic growth and its impact on the environment: a panel data analysis. Ecol. Indicat. 24, 324–333.

Badan Pusat Statistik (BPS). Integrated system of environmental-economic accounts of Indonesia [online]. Indonesia central Bureau of statisctics. various years, Avalilable at. https://www.bps.go.id/publication/2019/12/27/53e7360b49c122c58475d2c9/sistem-terintegrasi-neraca-lingkungan-dan-ekonomi-indonesia-2014-2018.html. (Accessed 11 September 2019).

Bolt, K., Matete, M., Clements, M., 2002. Manual for Calculating Adjusted Net Savings. Environment Department, World Bank, Wahsington DC. https://www.semanticscholar.org/paper/Manual-for-calculating-adjusted-net-savings-Clemens-Matete/8cad2cfc0f8437e8c99029c15b18d189d1606246. (Accessed 15 November 2019).

Chrysolite, H., Utami, A.F., Mahardika, D., Wijaya, A., 2020. Looking Past the Horizon : the Case for Indonesia ' S Long-Term Strategy for Climate Action. WRI Indonesia, Indonesia. https://files.wri.org/s3fs-public/looking-past-horizon.pdf. (Accessed 15 May 2020).

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Glob. Environ. Change 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

Da Motta, R, Amaral, C, 2000. Estimating timber depreciation in the Brazilian Amazon. Environ. Develop. Econ. 5 (01), 129–142. https://doi.org/10.1017/S1355770X00000097. (Accessed 15 November 2019).

De Bruyn, S., Ahdour, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., 2018a. Environmental Prices Handbook 2017. CE Delft. https://www.cedelft.eu/en/publications/2113/envionmental-prices-handbook-2017. (Accessed 15 November 2019).

De Bruyn, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., Ahdour, S., 2018b. Environmental Prices Handbook EU28 Version - Methods and Numbers for Valuation of Environmental Impacts. CE Delft. https://www.cedelft.eu/en/publications/2191/environmental-prices-handbook-eu28-version. (Accessed 15 November 2019).

Delft University of Technology, 2010. Ecocost 2007 LCA Data on Emissions and

Materials Depletion. Delft University of Technology, Netherlands, March, 2010. https://ecocostsvalue.com/EVR/img/Ecocosts%202007%20LCA%20data%20on%20emissions%20and%20materials%20depletion.xls. (Accessed 11 September 2019).

Domingo, E.V., Lopez-Dee, E.E.P., 2007. Valuation methods of mineral resources. In: 11th Meeting of the London Group on Environmental Accounting, pp. 26–30. Johannesburg. https://unstats.un.org/unsd/envaccounting/londongroup/meeting11/LG11_14a.pdf. (Accessed 15 November 2019). March.

European Environment Agency, 2014. Costs of Air Pollution from European Industrial Facilities 2008–2012 —, EEA Technical Report. https://doi.org/10.2800/23502. (Accessed 11 September 2019).

Hamilton, K., Clemens, M., 1999. Genuine savings rates in developing countries. World Bank Econ. Rev. 13, 2 https://doi.org/10.1093/wber/13.2.333.

Hertwich, E.G., van der Voet, E., Tukker, A., 2010. Assessing the Environmental Impacts of Consumption and Production. Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. http://www.unep.fr/shared/publications/pdf/DTIx1262xPA-PriorityProductsAndMaterials_Report.pdf. (Accessed 15 November 2019).

Jin-nan, Wang, Fang, Y., Hong-qiang, J., Dong, C., et al., 2008. A Framework of Pollution-Based Environmental and Economic Accounting for China. Chinese Academy for Environmental Planning, Beijing, p. 100012.

Li, V., Lang, G., 2010. China's "Green GDP" experiment and the struggle for ecological modernisation. J. Contemp. Asia 40 (1), 44–62. https://doi.org/10.1080/00472330903270346.

Margono, B.A., Potapov, P.V., Turubanova, S., Stolle, F., Hansen, M.C., 2014. Primary forest cover loss in Indonesia over 2000-2012. Nat. Clim. Change 4, 730–735. https://doi.org/10.1038/nclimate2277.

Obst, C., Vardon, M., 2014. Recording environmental assets in the national accounts. Oxf. Rev. Econ. Pol. 3 (1), 126–144. https://doi.org/10.1093/oxrep/gru003.

OECD, 2019. OECD Green Growth Policy Review of Indonesia 2019. Organisation for Economic Co-operation and Development.

Pearce, D.W., Atkinson, G.D., 1993. Capital theory and the measurement of sustainable development: an indicator of "weak" sustainability. Ecol. Econ. 8 (2), 103–108. https://doi.org/10.1016/0921-8009(93)90039-9.

Perman, R., Ma, Y., McGilvray, J., Common, M., 2011. Natural Resource and Enviromental Economics, fourth ed. Pearson Addison Wesley.

Pirmana, V., Alisjahbana, A.S., Hoekstra, R., Tukker, A., 2019. Implementation barriers for a system of environmental-economic accounting in developing countries and its implications for monitoring sustainable development goals. Sustainability 11 (22). https://doi.org/10.3390/su11226417. (Accessed 15 November 2019).

Repetto, R., Magrath, W., Wells, M., Beer, C., Rossini, F., 1989. Wasting Assets: Natural Resources in the National Income Accounts. World Resources Institute.

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J.H., Theurl, M.C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.H., de Koning, A., Tukker, A., 2018. EXIOBASE 3: developing a time series of detailed environmentally extended multi-regional input-output tables. J. Ind. Ecol. 22 (3), 502–515. https://onlinelibrary.wiley.com/doi/epdf/10.1111/jiec.12715. (Accessed 11 September 2019).

Steen, B., 2015. EPS 2015d:1 Including and excluding climate impacts from secondary particles. Report No, 2015:4a and 2015:4b. https://www.lifecyclecenter.se/publications/eps-2015d1-excluding-climate-impacts-from-secondary-particles/. (Accessed 11 September 2019).

United Nations, 2005. Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003, Studies in Methods, Rev.1. United Nation, New York.

United Nations, 2014. In: System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting. United Nations, New York. https://seea.un.org/content/seea-central-framework-1. (Accessed 15 November 2019).

U.S. Bureau of the Census, 2008. Pollution Abatement Costs and Expenditures (PACE) Survey. https://www.epa.gov/environmental-economics/pollution-abatement-costs-and-expenditures-2005-survey. (Accessed 11 September 2019).

Vincent, J., Casteneda, B., 1997. Economic Depreciation of Natural Resources in Asia and Implications for Net Savings and Long-Run Consumption. Harvard - Institute for International Development. Development Discussion Paper No. 614. https://ideas.repec.org/p/fth/harvid/614.html. (Accessed 15 November 2019).

WCED, 1987. Our Common Future, World Commission on Environment and Development. Oxford University Press, Oxford.

World Bank. Industrial Pollution Projection System (IPPS). https://datacatalog.worldbank.org/dataset/wps1431-ipps-pollution-intensity-and-abatement-cost/resource/7972b102-9c7b-4146-8df2. (Accessed 11 September 2019).

World Bank, 1994. Economy-Wide Policies and the Environment: Emerging Lessons from Experience. Washington DC.

World Bank, 1997. Five Years after Rio: Innovations in Environmental Policy. Washington DC. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/738661468181751334/five-years-after-rio-innovations-in-environmental-policy. (Accessed 15 November 2019).

World Bank, 2006. Where Is the Wealth of Nations? Measuring Capital for the 21st Century. Washington DC. https://openknowledge.worldbank.org/handle/10986/7505.

Xia, G., Wang, J., Lei, M., Xie, J., Gao, M., Zhou, H., 2006. International Experiences with Environmental and Economic Accounting". Washington DC.

Yuniarti, P.I., 2013. An indicator for sustainable development in Indonesia: genuine net saving. Rev. Indones. Econ. Bus. 4.

Yusuf, A.A, Pirmana, V., 2009. Estimates of the Green Domestic Product 2004-2007 and Green Regional Domestic Product 2005 for Indonesia. Report to the State Ministry of the Environment, Jakarta.

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