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Research article

Sustainable wastewater management in Indonesia's fish processing industry: Bringing governance into scenario analysis

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ABSTRACT

The government of Indonesia has pledged to meet ambitious greenhouse gas mitigation goals in its Nationally Determined Contribution as well as reduce water pollution through its water management policies. A set of technologies could conceivably help achieving these goals simultaneously. However, the installation and widespread application of these technologies will require knowledge on how governance affects the implementation of existing policies as well as cooperation across sectors, administrative levels, and stakeholders. This paper integrates key governance variables–involving enforcement capacity, institutional coordination and multi-actor networks–into an analysis of the potential impacts on greenhouse gases and chemical oxygen demand in seven wastewater treatment scenarios for the fish processing industry in Indonesia. The analysis demonstrates that there is an increase of 24% in both CH_4 and CO_2 emissions between 2015 and 2030 in the business-as-usual scenario due to growth in production volumes. Interestingly, in scenarios focusing only on strengthening capacities to enforce national water policies, expected total greenhouse gas emissions are about five times higher than in the business-as-usual in 2030; this is due to growth in CH_4 emissions during the handling and landfilling of sludge, as well as in CO_2 generated from the electricity required for wastewater treatment. In the scenarios where there is significant cooperation across sectors, administrative levels, and stakeholders to integrate climate and water goals, both estimated chemical oxygen demand and CH_4 emissions are considerably lower than in the business-as-usual and the national water policy scenarios.

1. Introduction

Leading up to the 23rd Conference of the Parties (COP 23) to the United Nations Framework Convention on Climate Change (UNFCCC), the government of Indonesia introduced its Nationally Determined Contribution (NDC). The NDC stated that Indonesia would aim to reduce greenhouse gas (GHG) emissions by at least 29% below business-as-usual (BAU) projections by 2030. A higher pledge of 41% below BAU by 2030 was also submitted contingent upon international financial and other forms of support. Indonesia's NDC breaks down these pledged reductions by sector, outlining possible contributions from key emission sources (Republic of Indonesia, 2016). The NDC emphasizes reductions from preserving Indonesia's forests and shifting to renewable energy; the land use and energy sectors are significant contributors to overall emissions in Indonesia (Wijaya et al., 2017). Yet the NDC also references reducing emissions of GHG from industrial wastewater management.

Indonesia is not only the world's fourth largest populated country, but one of its largest fish and seafood producers. However, due in part to the fast growth of seafood and other industries, more than 70% of Indonesia's rivers are classified as "polluted" (Lorenzo and Kinzig,

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2019). To improve water quality, the government of Indonesia, with support from international organizations, created The Program for Pollution Control, Evaluation and Rating (PROPER). PROPER disseminates color-coded ratings of companies' pollution management performance to generate the kind of public and peer pressure that can induce industrial compliance with national pollution control standards (Torres and Kanungo, 2003). Among the industries covered by PROPER, the fish processing industry performs at the lowest level in terms of environmental performance. Therefore, the Indonesian Ministry of Environment and Forests is making considerable efforts to adopt and implement appropriate wastewater treatment methods (Consultants Co, 2015). Many of these efforts can help achieve water quality and climate change objectives while contributing to the Sustainable Development Goals (SDGs).

The above reasons suggest that Indonesia is an important case to examine the impacts of climate and wastewater management goals in its own right. A few additional factors clarify why Indonesia's experience could offer lessons for other rapidly industrializing countries. Like many other fast-growing countries, although Indonesia has tightened wastewater regulations, the resources to enforce regulations tend to be limited (Asian Development Bank, 2005). As is often the case in rapidly developing countries, industrial capacity to generate effluent outpaces government capacities to regulate pollution. High levels of water pollution are additionally a result of limited access to wastewater management technologies, especially for small and medium sized enterprises (SMEs). Yet another contributing factor behind these challenges is the difficulties of scaling wastewater treatment technologies. Even if a single enterprise installs these technologies, whether many small and frequently dispersed emission sources follow suit is far from guaranteed.

This article suggest that more attention needs to be placed on how governance can help overcome some of the above policy and institutional challenges so as to facilitate the adoption and spread of key technologies. More concretely, governance—the exercise of authority in the pursuit of one or more policy goals—is critical to making links between pollution and climate issues. It also influences whether agencies at multiple levels enforce regulations. It is finally related to whether this sufficient interagency coordination and networks enable the spread of successful solutions (Nanda, 2006; Stoker, 1998; Hewitt de Alcántara, 1998). However, while many of the models developing emission reduction scenarios demonstrate positive effects of sustainable wastewater management on climate change and water pollution, few systematically consider how different levels of governance influence policy enforcement, coordination and networking. The omission of these considerations may lead to modelling results and policy recommendations that diverge sharply from reality (Hourcade and Crassous, 2008).

The main contribution of this article is to better capture that reality by integrating insights on governance into modelling-focused climate policy and sustainable development research. In recent years, some studies have sought to bridge quantitative assessment modelling with qualitative transitions research. For example, a branch of sustainable transitions research has sought to bring in "the types of actors, their goals, strategies, and resources as well as institutional changes" contributing to the spread of sociotechnical innovations (De Cian et al., 2017). However, there remains considerable scope to translate how key actors, agencies and institutions can be incorporated into scenarios that often feature in integrated assessment modelling. A novel way forward is to use research on governance to provide insights into three sets of considerations influencing the spead and scale of technology changes. These insights are critically important because it is often asserted in the water sector that effective resource management is more a governance than technical issue (Casiano Flores et al., 2017; Grigg, 2011). To a significant degree, these three sets of factors also mirror the main modes of governance in recent work on sustainable water governance (Pahl-Wostl, 2019).[1]

The first set of governance insights falls under what is often called government capacity and effectiveness. As that title suggests, these sets of issues involves governments having sufficient financial and human resources to implement a variety of their own regulations (Kaufmann et al., 2010; Rock, 2002). Capacity warrants attention both because responsibilities for implementing climate and wastewater management regulations are increasingly delegated to often underfunded local governments (Asian Development Bank, 2005; Casiano Flores et al., 2019). These issues also merit reflection because the lack of resources cannot only contribute to well-studied implementation gaps (Lester and Goggin, 1998). Finally, capacity is pertinent because increasing resources without sufficient institutional coordination could paradoxically lead to more GHG emissions (see Section Three).

The second set of governance insights concerns whether effective coordination exists between climate and pollution control agencies within and across levels of decision making. Insufficient horizontal coordination can create a disconnect between climate mitigation and development policies, including water management and pollution control policies (Arens et al., 2014; Corfee-Morlot et al., 2009; Peters, 1998). On the other hand, insufficient vertical coordination could lead to challenges acquiring the financial and other resources needed to bring promising technologies to scale. Coordination troubles within and between levels can result bureaucratic turf wars and incoherent policies that are familiar to those working on integrated water resource management and many other contexts (Biswas, 2008; Jones et al., 2019).

The third set of governance considerations involves the spread of successful examples using networks of business and civil society actors in and outside governments or what is often called governance "beyond the government" (Bressers and Kuks, 2013). These networks rely more on informal institutions, trust and voluntary agreements; they also have a higher degree of flexibility that facilitates the sharing of information on innovative solutions and collective learning about which technologies work in which contexts. Networks can complement more the more formal institutions and structures discussed above (Pahl-Wostl, 2019).

Water management experts have cautioned against applying one-size-fits all governance recommendations without an appreciation of context (Ingram, 2013; Suhardiman et al., 2015). However, in this case the three sets of factors outlined above—capacity, coordination, and networks—are related to development that have helped to shape Indonesia's policy and institutions. More concretely, several of relevant changes followed decentralizing reforms in the 1990s that delegated significant enforcement responsibilities for environment regulations to local governments. These reforms did not, however, ensure sufficient numbers of properly trained staff were employed to manage assigned tasks (Rabasa and Chalk, 2001). This meant that regulation No. 82/2001 (water quality), No. 7/2004 (water resources management) and other key sectoral policies (see Table A1 supplement) often suffered from implementation gaps (Arcowa, 2018). These gaps explain why the fish processing industry encountered hurdles ranging from shortages of technical expertise to low levels of government funding (Apip et al., 2015). They also help to understand why simpler aerated treatment ponds became more common than activated sludge technologies or other cleaner technologies (AECOM and Sandec 2010).

Recently, there have been some developments involving governance that may help close these implementation gaps. Some of these involve increases in institutional capacity. For instance, observers have pointed

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[1] Pahl-Wostl (2019) argue for meta-governance where governments employ a mix of hierarchies, markets and networks to steer decisions to more sustainable water policies. The third set of considerations in this article combines markets and networks.

out that the growing stringency of wastewater effluent discharge regulations have led to improved water quality in parts of Indonesia (Soedjono, 2018). Others have suggested that Indonesia has embraced the aforementioned PROPER programme to boost compliance with regulations (Consultants Co, 2015; Torres and Kanungo, 2003).

Another notable and relevant set of governance reforms involves Indonesia's response to climate change. Since 2011, Indonesia has placed growing attention to climate policy. This has entailed a core group of experts working with the National Development Planning Agency (BAPPENAS) and relevant line ministries to draft climate change plans. A coordinating unit and several sectoral working groups have been established to better align strategies and plans. To some extent, Indonesia's NDC reflects this cross-sectoral or horizontal integration as it draws from series of sector specific policies and regulations that extend out to 2030. A related set of reforms involves the sharing of plans with provincial and lower level local governments that are then expected to further specify and tailor their content to local contexts (Wijaya et al., 2017).

A final set of reforms has centered on engaging the private sector in wastewater treatment in the fish processing industry. Much of this interest has revolved around developing a regulatory framework for public and private partnerships (PPP). That framework would involve both national and local governments working with overseas donors to attract investments in advanced wastewater treatment infrastructure and technologies. It would also make it a point to engage private sector early and often in the planning (i.e. construction, operation and maintenance) (Asian Development Bank, 2019). A possible consequence of these arrangements is that there would be higher levels of compliance with regulations as a result of the dissemination of cleaner technologies. One of the few locales as Muncar-Banyuwangi that have taken actions in minimizing their wastewater discharges with standards exceeding national regulations suggest just such a possibility (Widodo, 2016).

This study therefore attempts to bring the aforementioned considerations involving governance into an analysis of water pollution and greenhouse gas (GHG) emissions from several wastewater treatment scenarios in Indonesia's fish processing industry. As such, it will not only contribute to wastewater management research specifically, but integrate qualitative insights into quantitative assessment research generally (Meuleman, 2015). In the process, it will help fill an important research gap on whether what is feasible in a model can be achieved in applied settings.

The rest of the paper is structured as follows: Section 2 presents the methods applied to project fish production to estimate Chemical Oxygen Demand (COD) load and GHG emissions up to 2030, along with a description of scenarios disigned to intergrate technological development and governance. Subsequently, in Section 3, the results are presented, including estimations on COD removal efficiencies, GHG emission reductions, together with an analysis of the co-benefits of the different scenarios included and political implications. Section 4 highlights the limitations of the study and lastly Section 5 presents the conclusions of the study with a focus on the way forward.

2. Material and methods

While the previous section suggested the possibility of three sets of governance reforms influencing the adoption and spread of wastewater treatment technologies, it did not offer insights into their implications for water pollution control or climate mitigation. The methods section outlines how those insights will be provided based on the rationale that COD removal efficiencies (%) and GHG emissions ($ktCO_2eq/year$) depend on how different forms of governance affect the type of wastewater treatment technology implemented, i.e., on the adoption of the different scenarios.

The first step is a description of the fish processing industry, followed by a summary of the methods used to estimate COD load and GHGs from the wastewater treatment in the fish processing industry in Indonesia until the year 2030, and then complemented by the description of scenarios. The method described in Gómez Sanabria et al. (2018) is applied to quantify the organic content and biogas generation from anaerobic wastewater treatment. GHG emissions are estimated based on Höglund-Isaksson et al. (2015). For detailed information on technologies implemented, variables and on assumptions and equations applied refer to the Supplement Section A3 and Section A4.

2.1. Wastewater from fish processing industry

Fish processing involves three main sets of activities: fish refrigeration, canning and fishmeal processing. The fish refrigeration plant is the where the first step occurs. The process consists of washing and sorting the fish into different groups for sale in packed boxes with ice. The fish to be frozen follows the same steps but requires refrigeration and storage until it is delivered (Björk and Schou Kongstad, 2016). The canning process involves three main sub-processes; reception of raw materials and ingredients, processing (including cooking, washing and canning, and final operations) (Valiño et al., 2007). The fishmeal process involves cooking, pressing, drying and grinding the fish (Green, 2016).

Wastewater from the fish processing contains a mixture of organic substances, nutrients, oil and fats (Purwanti et al., 2018). The characteristics of the effluent varies between the different processes but also depends on the composition of the raw fish (Table 1).

2.2. Fish production projections, COD load and GHGs estimations

The paper uses derived COD load in untreated wastewater to assess the organic load removal efficiencies and GHG emissions from different wastewater treatment options. The COD amounts are derived from production volumes combined with wastewater generation rates and COD generation factors (Höglund-Isaksson et al., 2018). National production volumes (from fish catchment and aquaculture combined) are taken from FAO-Fisheries and aquaculture statistics (FAO, 2018). Future production projections to 2030 are based on the Baseline Scenario presented in the "Fish to 2030" (World Bank, 2013) and "Exploring Indonesian Aquaculture" (Phillips et al., 2015) studies. No significant growth in captured fisheries is expected, therefore a 0.4% growth in fish catch is assumed for the whole period until 2030 (Ipsos Business Consulting, 2016; World Bank, 2013). Projections in aquaculture production assume 5.6% annual growth (Phillips et al., 2015). The main growth driver for fisheries in Indonesia is high domestic but also international demand (Ipsos Business Consulting, 2016).

Regional production volumes are based on the regional percentage of production by fish type presented in Phillips et al. (2015) and on the number and size of factories in each region. The regions included are Java, Sumatra, Kalimantan, Sulawesi and Maluku-Papua (Figure A1 in the supplement).

The quantification of COD in untreated industrial wastewater is carried out by applying the IPCC method (IPCC, 2006, Volume 5, Chapter 6, Equation 6.4 and Equation 6.6). The assessment of the GHG emissions and energy generation potentials is based on the removal efficiencies and application rates of the different wastewater technologies adopted. COD removal efficiencies, CH_4 emission factors [$ktCH_4$/kt COD removed], biogas composition and electricity consumption [kWh/kg COD removed] are based on the IPCC Guidelines (2006), Consultants Co

Table 1
Characteristics of effluents of fish processing plants.

Process	Wastewater [m^3/ton]	COD load [kg/ton]	pH
Refrigeration plant	10–30	2–6	6.9
Canning factory	15–30	2.25–4.5	3.8–6.4
Fishmeal factory	12	12	6–7

Source: Based on (Chowdhury et al., 2010)

(2015) and Spokas et al. (2006). Regional CO_2 emission factors [$ktCO_2$/KWh] are adopted from Directorate General of Electricity, Ministry and Mineral Resources, Indonesia; 2016 - Emission factor reference official document (see supplement section A4).

2.3. Wastewater treatment scenarios

Seven different scenarios for wastewater management are developed in the timeframe to 2030. The applied wastewater treatment technologies originate from the study: 'Co-benefits of the wastewater treatment technologies: Indonesia fish processing industry' (Consultants Co.,Ltd, 2015). The phase-in of the technology assumes implementation of 15% by 2020, 50% by 2025 and 100% by 2030 for the 'Business as Usual', 'National wastewater policy', and 'Climate change policy scenarios', respectively. The phase-in of the technology for the further four co-benefit scenarios depends on the areas or forms of governance that are strengthened. For vertical and horizontal integration, a maximum technological phase-in of 80% by 2030 is assumed. The multi-stakeholder network form of governance scenarios allows for 100% of technological phase-in by 2030. Scenarios consider the national effluent standards of the fish processing industry (Decree of Ministry of Environment& Forestry no.5/2014) and the GHG emission reduction targets under the NDC.

Description of the scenarios developed are presented in Table 2. Each scenario is designed based on the three main elements: policy, form of governance and technology. Policies adopted are according to the policies presented in the supplement A1 – Table A1 and are in line with Indonesias's NDC. Assumptions on the form of governance are based on the literature review presented in the introduction. Technological development is based on Consultants Co.,Ltd (2015). A detailed description of scenario narratives is presented in the supplement Section A6 - Table A4.

Table 2
Description of the scenarios.

Scenario	Policies	Forms of governance	Technology
Business-as-usual (BAU)	Current situation - no further enforcement	Current situation	Untreated/ anaerobic lagoons
National Wastewater Policy (NWP)	National wastewater policy	No coordination between wastewater and climate agencies	Aeration lagoon plus Activated sludge
Climate Change Policy (CCP)	Climate change policy	No coordination between wastewater and climate agencies	Swimbed
Co-benefits vertical horizontal coordination (CB1vh)	National wastewater policy and climate change policy	Vertical horizontal coordination	Up-flow Anaerobic Sludge Blanket (UASB) plus Activated Sludge (with gas recovery and used).
Co-benefits vertical horizontal coordination (CB2vh)	National wastewater policy and climate change policy	Vertical horizontal coordination	Up-flow Anaerobic Sludge Blanket (UASB) plus Swimbed (with gas recovery and used).
Co-benefits multi-stakeholder network (CB1ms)	National wastewater policy and climate change policy	Multi-actor network	Up-flow Anaerobic Sludge Blanket (UASB) plus Activated Sludge (with gas recovery and used).
Co-benefits multi-stakeholder network (CB2ms)	National wastewater policy and climate change policy	Multi-actor network	Up-flow Anaerobic Sludge Blanket (UASB) plus Swimbed (with gas recovery and used).

The scenarios are implemented at both the national and sub-national levels. Sub-national regions are selected based on the relative contribution to national production of key aquaculture commodities and farming systems (Phillips et al., 2015) and on information available regarding the distribution of fish factories and number of employees (Consultants Co.,Ltd, 2015). As a result, scenarios have been developed for the following sub-national regions: Java, Sumatra, Kalimantan, Sulawesi and Maluku-Papua. Implementation of costs for the different scenarios were not included in this analysis due to a lack of information.

2.4. Limitations

The study is based on information resulting from a pilot project in which the actual technology tested is the swimbed technology. Some of the parameters used for the development of the analysis are derived from values provided by Consultants Co. Ltd (2015). Retention times, wastewater generation rates, organic load rates, efficiencies on biogas formation and biogas recovery are mostly based on default values which do not differentiate the type of process e.g., refrigeration plant, canning factory and fish meal factory. It is also assumed that different processes operate in optimal conditions. However, it is well known that microbial community is extremely sensitive and, if not properly managed, the process would result in reduced biogas production (Munk et al., 2010).

It is further important to note that the quantification of N_2O is not included in this study. The reason it is not included is that the case study focused solely on CH_4 and CO_2 emissions. However, the authors are aware that N_2O is the third most powerful GHG, having a global warming potential that is 265 higher than CO_2 over a 100 year time horizon (IPCC, 2014) and causes long-term disturbances to the stratospheric ozone layer. N_2O emissions from wastewater treatment plants are the result of the nitrification and denitrification processes (Zheng et al., 2019) occurring mainly in the activated sludge units (Campos et al., 2016).

Regarding electricity generation, it is assumed that the average national fuel mix in electricity production is used in wastewater treatment plants. However, fuel mix might change at a sub-national or regional level. Though average regional emission factors for electricity production are used, the specific regional representation of fuel mix is not taken into account due to lack of relevant data.

The article analyses the implementation of technologies to reduce water pollution and GHGs at the last stage before the effluent enters the environment. Nonetheless, wastewater treatment should be looked at in a holistic manner as wastewater offers a huge potential for recovery of resources. In addition to energy generation, wastewater can also provide 'resources' such as bioactive compounds, antimicrobial agents and natural chemicals (Federici et al., 2009). Furthermore, water recycling and reuse is also important when implementing wastewater treatment systems (Chen et al., 2019).

The development of, *inter alia,* strategies integrating the circular economy framework, health-related aspects and corporate social responsibility could further contribute to the realization of the national sustainable development goals (SDGs). Such aspects—which are also reviewed in the conclusion—would likely further strengthen the case for improved wastewater treatment but an assessment of all of the benefits would require additional data that is not available to the authors.

Beyond the environmental benefits, costs are critical when selecting wastewater management treatment technologies. Factors influencing investment, operation and maintenance costs include flow rate, pollution load, number and type of treatment stages of the facility and removal efficiencies (Hernandez-Sancho et al., 2011). The cost aspect was not part of this study due to the lack of quantitative information in terms of construction, maintenance, and sludge disposal costs for the different technologies. Therefore, it was not possible to carry out the corresponding cost analysis which would be vital in a feasibility study to identify the potential economic constraints that could prevent the adoption of a specific technology system.

3. Results

This section summarizes the key results at the country and sub-national levels in terms of COD removal and GHG emissions from wastewater treatment in the fish processing industry.

3.1. COD removal efficiency

The maximum COD removal efficiencies are expected to be achievable upon the introduction and diffusion of the different treatment strategies and policies. Removal efficiencies show that there is significant potential to improve the removal of organic load and to reduce COD concentration in the wastewater effluent when relevant institutions have adequate human, financial and technological capacities and resources.

Reaching full implementation of NWP and CCP would require overcoming challenges in BAU regarding capacities and coordination in the corresponding institutions. When coming to the implementation of any of the co-benefit scenarios, overcoming these hurdles is even more challenging due to the need to align the agendas of vertical and horizontal (vh) regulatory agencies as well as working with multi-stakeholders and international organizations (ms).

The implementation of the different scenarios will result in an overall increase of COD removal efficiencies of around 12% (for all scenarios) compared to BAU in 2020, and between 43% (NWP) and 46% (for the other scenarios) compared to BAU in 2025. By 2030, the implementation of CCP, $CB1_{ms}$ and $CB2_{ms}$ would result in higher removal efficiencies (98.6%–98.4%) as a result of successful coordination and additional international support in the case of multi-stakeholder (ms) scenarios. Interestingly, $CB1_{vh}$ and $CB2_{vh}$ show the lowest COD removal efficiency (79%) arising from the lack of involvement of multi-actor networks (see Figure A1 in the supplement).

Fig. 1 shows that, although there is an improvement over time in the reduction of COD concentration and load in the effluent resulting from the implementation of the different scenarios, it would not be possible to fully comply with the Indonesian wastewater regulations before 2030.

In the BAU scenario, current technology prevails up to 2030 with a maximum removal efficiency of COD at 2.8%. The low removal efficiency is a consequence of an increase in the national projection of aquaculture commodities production due to insufficient enforcement of the wastewater standards set for the fish processing industry. Full implementation of NWP, CCP $CB1_{ms}$ and $CB2_{ms}$ by 2030 is expected to translate into compliance or even over-compliance with national effluent standards for different fish industry processes in terms of COD concentration (refrigeration plant 200 mg/l, caning 150 mg/l and fish meal factory 300 mg/l) and COD load (refrigeration plant 2.0 kg/ton, caning 2.25 kg/ton and fish meal factory 3.6 kg/ton). Full implementation of $CB1_{vh}$ and $CB2_{vh}$ by 2030 is, however, not expected to be sufficient to meet regulatory standards; rather COD concentration standards are expected to be exceeded by 40% for the refrigeration plant, 53% for the caning and 6% for the fishmeal factory. Concerning COD loads, the standard is expected to be exceeded by 40% for the refrigeration plant and 30% for caning. Full implementation of $CB1_{vh}$ and $CB2_{vh}$ by 2030 would, however, meet the COD load standard for the fish meal factory (Fig. 1). The estimation of the COD discharge load per year after implementation of the different technologies by region and at country level is presented in the Supplement Table A4 and A5.

3.2. Greenhouse gas emissions

Estimates of CH_4 and CO_2 emissions from fish processing wastewater handling have been carried out for the different scenarios (Fig. 2). All GHG are expressed in CO_2eq terms assuming a global warming potential of 100 years (IPCC AR5, 2014). Methane emissions in this article are emissions from the wastewater treatment process at the discharge point and during sludge treatment. Emissions of CO_2 refer to emissions associated with the production and consumption of electricity required for reduction of COD in different processes. The results illustrate that both the choice and scaling of alternative wastewater treatment strategies influence whether the overall impact on GHG emissions will be positive or negative in comparison to BAU.

In the BAU, there is an increase (by 24%) in both CH_4 and CO_2 emissions between 2015 and 2030. This is partly driven by an expected increase in production volumes and partly resulting from the low application of anaerobic lagoons and inappropriate management of the technology. Moreover, considering the current situation, larger quantities of wastewater from fish processing industries are released without previous treatment. Consequently, the circumstances do not fully favor the formation of anaerobic conditions, thus lowering the capacity of CH_4 formation from untreated wastewater. Since anaerobic lagoons require no or little energy (EPA, 2002), emissions of CO_2 related to energy consumption are small.

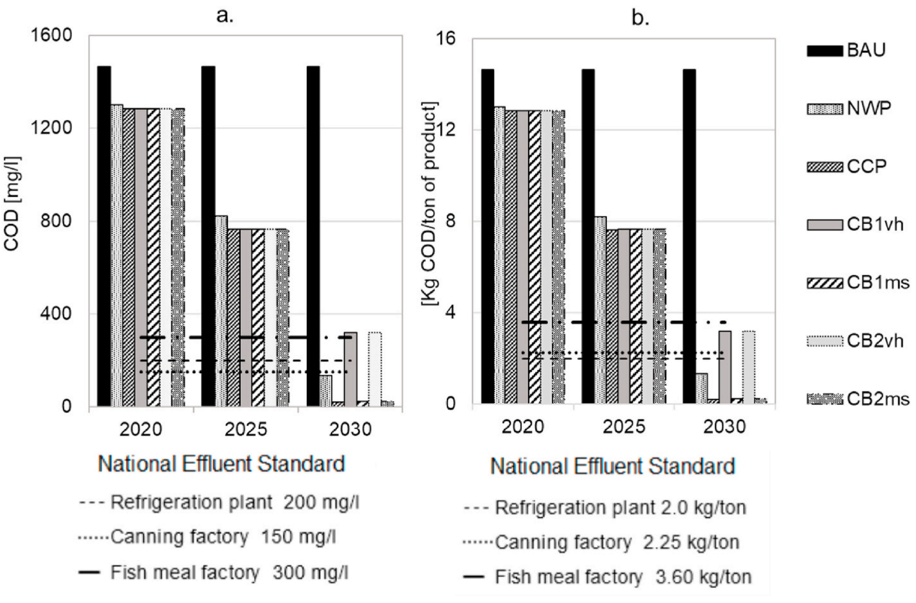

Fig. 1. a. Effluent COD concentration b. Effluent COD load.

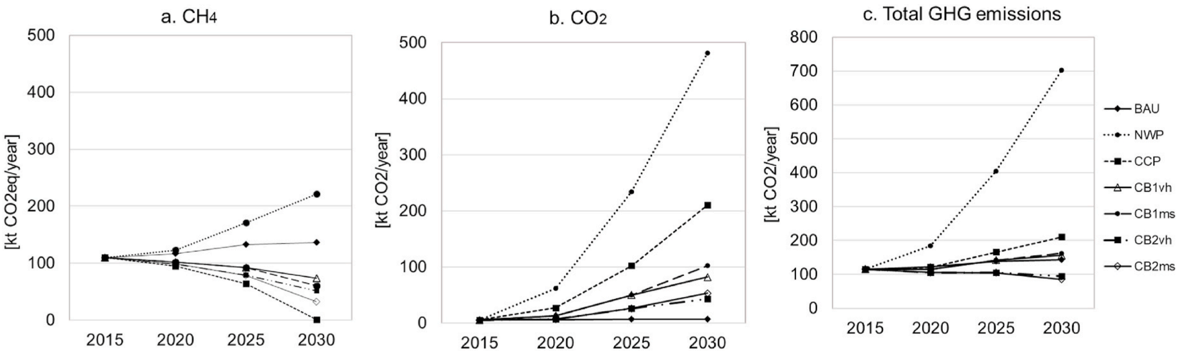

Fig. 2. a. CH$_4$, b. CO$_2$ and c. total GHG emissions from wastewater treatment in fish processing industry – Indonesia. Regional figures can be found in the Supplement Figure A2.

In the NWP, total GHG emissions are expected to be about five times higher than BAU in 2030 (Fig. 2c). An expected increase in CH$_4$ emissions arise from anaerobic conditions during handling and landfilling of the sludge, which more than outweigh the CH$_4$ emissions from the current lack of treatment (with some use of anaerobic lagoons) in the BAU. CO$_2$ emissions are expected to be considerably higher in the NWP than in the BAU, due to a higher electricity consumption required by the artificial aeration needed to stimulate biological oxidation in the treatment process.

At the same time, CH$_4$ emissions from the CCP, CB1$_{vh}$, CB1$_{ms}$, CB2$_{vh}$ and CB2$_{ms}$ are expected to be considerably lower than BAU due to the implementation of improved wastewater technologies. The full implementation of CCP is expected to generate the lowest CH$_4$ emissions, followed by CB2$_{vh}$ and CB2$_{ms}$ (Fig. 2a). One of the advantages of the CCP is that the technology (swimbed) allows for longer retention times due to sludge recycling (Rouse et al., 2004), which reduces sludge production along with CH$_4$ emissions from its management. However, this technology has high electricity requirements resulting in high CO$_2$ emissions, which offset the reduction in CH$_4$ emissions in terms of global warming impact (Fig. 2b).

Given an assumption that the average national fuel mix in electricity production is used in the energy supply to wastewater treatment, CO$_2$ emissions in 2030 are expected to be 69 times higher in the NWP than in BAU. This is partly due to a higher electricity consumption in the NWP (2.97 GWh/kt COD removed) than in the BAU (1.39 GWh/kt COD removed) and partly because in the CCP, CB1$_{vh}$, CB1$_{ms}$, CB2$_{vh}$ and CB2$_{ms}$ technologies are expected to increase electricity consumption and associated CO$_2$ emissions compared with BAU.

It is estimated that the electricity required in NWP will be 562 GWh in 2030, which is 44% higher than CCP, with the latter also using aerobic systems but with a different technology. From the type of technology adopted in CB1$_{vh}$, CB1$_{ms}$, CB2$_{vh}$ and CB2$_{ms,}$ it would be possible to recover and use the biogas generated. The technology adopted in the CB2 set of scenarios requires 30% less electricity per kt COD removed than the technology adopted in the CB1 set. Also, the use of the own biogas as a source of electricity would in 2030 replace 36% and 52% of the required external energy in the CB1 and CB2 sets of scenarios, respectively (Fig. 3).

The expected total GHG emissions in 2030 turn out higher than BAU for all technologies except the CB2 set of scenarios (Fig. 2c). The latter combines an Upflow Anaerobic Sludge Banked technology with Swimbed technology and recovers the biogas to generate electricity for own-plant use. In general, scenarios implementing aerobic treatment alone would result in higher electricity consumption as aeration uses up around 60%–70% of total energy required for the wastewater treatment process (Maktabifard et al., 2018). The advantage of implementing the CB2$_{ms}$ scenario would then be the combination of anaerobic treatment which generates CH$_4$ that can be used to supply part of the electricity required by the swimbed technology (regional figures displaying GHG emissions can be found in the Supplement Figure A3).

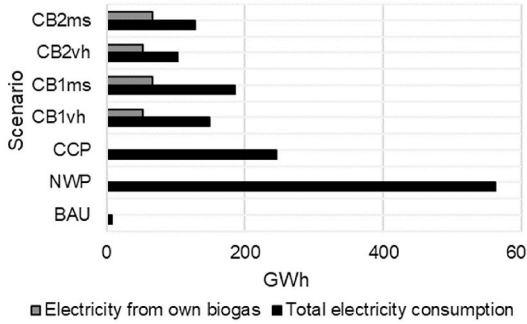

Fig. 3. Electricity consumption wastewater treatment in fish processing industry in 2030 – Indonesia.

Fig. 2c summarizes the total GHG emission trajectories for the different scenarios. The NWP is expected to generate the highest GHG emissions, owing to the largest emissions from electricity consumption. In contrast, the Co-Benefits 2 multi-stakehodler network scenario (CB2$_{ms}$) has the lowest GHG emissions due to a lower energy consumption coupled with recovery and use of the biogas generated from the wastewater treatment to offset part the energy required for the wastewater treatment process.

3.3. *Analysing the co-benefits of wastewater treatment*

The implementation of NWP and CCP do not deliver co-benefits in terms of simultaneous reduction of COD and GHG emissions due to the absence of multi-level, multi-stakeholder governance. In contrast, the set of CB scenarios, which address environmental concerns by reducing COD concentration in the effluent while reducing GHG emissions from wastewater treatment through multi-level governance, deliver those co-benefits. In that sense, the scenario providing the maximum benefits is the one which combines the highest COD removal efficiencies with the lowest GHG emissions per unit of COD removed. This, in turn, can ensure compliance with the national wastewater standards while reducing GHG emissions from wastewater treatment and therefore supporting the achievement of the Indonesian NDC targets.

Fig. 4 shows the relation between GHG emissions and COD removal efficiency. The adoption of any alternative scenarios to the BAU, except for the CB1$_{vh}$ and CB2$_{vh}$, would result in compliance with the national effluent standards by 2030. Interestingly, Fig. 4 also shows the highest GHG emissions expected from the implementation of NWP. CCP, CB1$_{ms}$ and CB2$_{ms}$ depict similar COD removal efficiencies, nevertheless, CB2$_{ms}$ (UASB plus swimbed) provides the maximum benefits in terms of GHG emissions and is the only option that improves both COD effluent concentrations and mitigates climate impacts. By 2030, the CB2$_{ms}$ removal

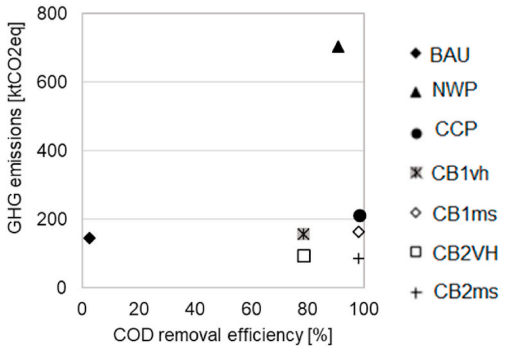

Fig. 4. Multiple benefits of the analysed scenarios.

efficiency would reach a maximum of 98.4% COD removed, while reducing GHG emissions by 60% compared to BAU. GHG emissions in the $CB2_{ms}$ is also 47% lower than in $CB1_{ms}$ and 57% lower than in CCP.

A summary of the main achievements resulting from the implementation of the different scenarios in the year 2030 is presented in Table 3. The scenario providing the maximum co-benefits is highlighted in gray.

3.4. Policy implications

The Indonesian government has established ambitious targets for reducing GHG emissions but also strict wastewater treatment standards. In an attempt to achieve sustainable development, Indonesia is seeking policies that can provide multiple benefits from climate change mitigation and water pollution prevention. Therefore, the identification and dissemination of appropriate wastewater treatment strategies are vital.

Despite strict wastewater legislation, appropriate wastewater treatment facilities (especially in the fish processing industry), are still lacking. This results in effluents with high pollution load which, on the one hand, could potentially create anaerobic conditions facilitating the formation of methane and, on the other hand, contaminate watercourses. If current conditions are maintained, the pressure on water quality will further increase, thereby threatening not only environmental but also health and social conditions. By 2030, without the enforcement of wastewater legislation and taking into account a growth in total production volumes by 24%, COD concentration in the effluent could be as much as 6–7 times higher than national standards for the fish processing industry. Strengthening capacities to implement existing wastewater regulations is therefore essential (Kaufmann et al., 2010; Rock, 2002).

Currently available technology and effective implementation of existing wastewater legislation could decrease water pollution and reduce GHG emissions from wastewater treatment. However, this is only possible with careful choices of treatment technologies and the source of energy. Such choices must consider the COD removal efficiency, the conditions for CH_4 formation and release in the different treatment stages, as well as the energy source and CO_2 emissions from additional electricity requirements. Here again, while enforcement of policies for the outlined co-benefits will be *necessary* for meeting established targets, focusing exclusively on capacities may not be *sufficient* for a sustainable future. To reach both effluent and climate targets in the $CB2_{ms}$—where COD concentration in the effluent would likely be eight times lower than the standard fish processing industry limits and GHG emissions would be 60% lower than in the BAU or around 0.38 $ktCO_{2eq}$/kt COD removed—multiple levels of governments and stakeholders need to work together on shared purposes and common goals (Arens et al., 2014; Corfee-Morlot et al., 2009; Peters, 1998).

In fact, the aforementioned benefits will require a focus on multilevel governance that brings together pollution and climate institutions at national and local levels as well as different networks or stakeholders and international institutions (Pahl-Wostl, 2019; Bressers and Kuks, 2013). Without context-appropriate coordination at different levels (Ingram, 2013), the benefits offered by the $CB2_{ms}$ would not be realized. The misalignment of efforts between agencies and actors might lead to an overly narrow focus on achieving a single objective i.e., water pollution, without realizing it jeopardize progress on another objective i.e., GHG mitigation. Therefore, climate objectives will need to be incorporated into local urban policies (Gouldson et al., 2016). The good news is that some studies have shown that reaching climate goals i.e., NDC targets, requires actions at the sub-national level. An additional piece of good news is that initiatives as ‘United Cities and Local Governments’ are working to reduce GHGs emissions locally and achieve national GHGs reduction targets (Betsill and Bulkeley, 2006). These studies and actions are also supported by work that suggests that national governments can provide the financing to bring to scale promising local innovations (Suhardiman et al., 2015).

Hence, placing more attention on governance for managing wastewater and climate change in Indonesia could help overcome the challenges faced by industries in relation to budget, technology transfer and capacity building (Arcowa, 2018) and support the move towards a reduction in both water pollution and GHGs. The transition to a multi-level, multi-stakeholder forms of governance could support the identification of shortcomings related to the implementation of the current wastewater legislation as well as open several opportunities for policy frameworks targeting multiple objectives.

4. Conclusions

This article offers a unique perspective on the governance reforms needed to achieve climate and wastewater treatment goals. This follows research that argues that managing wastewater is frequently a governance issue (Casiano Flores et al., 2017; Grigg, 2011). It provides that perspective by integrating work on qualitative governance and quantitative modelling research. While there are some limitations to this

Table 3
Achievements by scenario in 2030.

Scenario	Policies	Form governance	Technology	Total GHG emissions [kt CO_2eq/year]	COD removal efficiency [%]	Electricity replaced by own biogas [%]
BAU	Current situation	Current situation	Untreated/anaerobic lagoons	143	3	0
NWP	NWP	No coordination	Aeration lagoon + Activated Sludge	703	91	0
CCP	CCP	No coordination	Swimbed	211	99	0
CB1vh	NWP + CCP	Vertical-horizontal coordination	UASB + Activated Sludge + Energy recovery and use	156	79	36
CB1ms	NWW + CCP	Multi-actor network	UASB + Activated Sludge + Energy recovery and use	162	98	36
CB2vh	NWP + CCP	Vertical-horizontal coordination	UASB + Swimbed + Energy recovery and use	94	79	52
CB2ms	NWW + CCP	Multi-actor network	UASB + Swimbed + Energy recovery and use	85	98	52

approach—i.e. challenges of capturing dimensions of governance or lack of important cost data—there is also clear and compelling messages that should draw the attention of policymakers in and outside of Indonesia.

These messages begin with the claim that NDCs and wastewater regulatory standards currently can serve as a starting point for mitigating climate change and improving water quality. However, a critical finding is that it is not simply strengthening climate and wastewater management policies and measures but aligning policymaking institutions and decision making processes. A related finding is that strengthening government capacity without coordination can lead to the more stringent enforcement of treatment measures focused solely on COD removal that can surpisingly increase GHG emissions. Therefore, decision-makers need to consider governance reforms that consistently deliver policies and measures that exploit the maximum COD removal efficiency as well as the maximum GHG mitigation potential.

Another policy-relevant finding is that it is possible to quantify the benefits that could potentially derive from enhancing governance across levels and actors. The analysis shows that maximum co-benefits would likely result from multi-level, multi-stakeholder forms of governance that is inclined to support the Up-flow Anaerobic Sludge Banked, including gas recovery and use with a Swimbed technology (Scenario $CB2_{ms}$). The substitution of electricity use from external sources due to the recovery and use of own-biogas is one of the main advantages of adopting $CB2_{ms}$. The implementation of CB2 will provide 52% of the electricity required for wastewater treatment, thus, replacing fossil fuels and reducing GHG emissions from electricity consumption. However, the success of $CB2_{ms}$ fully depends on the cooperation and coordination at all levels of governance.

The article also points to a potentially fruitful area of research that could help strengthen that cooperation: that is, more systematically accounting for potentially desirable features of governance. There has been notable headway in assessing some of the key properties and characteristics of good governance across countries that could be useful in this regard. There is also important research that draws on multi-criteria analysis to benchmark the quality of governance in cities (including work on aspects such as performance and efficiency) in cities such as Lisbon. As this work notes, one of the main benefits of this approach is the participatory process of benchmarking performance actually motivates stakeholders to improve performance and efficiency (da Cruz and Marques, 2014; Marques et al., 2015).

A final avenue for future research could focus on exploring strategies that more explicitly integrate the circular economy and co-benefits framework as one of the instruments to reach the national sustainable development goals. Strategies that could be investigated include water and energy use efficiency and material – water recycling. Furthermore, an analysis on the application of these technologies to the whole food industry could shed light on additional water pollution and climate benefits.

CRediT authorship contribution statement

Adriana Gómez-Sanabria: Conceptualization, Investigation, Methodology, Writing - review & editing. **Eric Zusman:** Conceptualization, Writing - review & editing. **Lena Höglund-Isaksson:** Conceptualization, Investigation, Methodology, Writing - review & editing. **Zbigniew Klimont:** Conceptualization, Writing - review & editing. **So-Young Lee:** Investigation, Writing - review & editing. **Kaoru Akahoshi:** Investigation, Writing - review & editing. **Hooman Farzaneh:** Investigation, Writing - review & editing. **Chairunnisa:** Investigation, 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.

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Appendix A. Supplementary data

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