Decision Support System for the Mitigation and Adaptation of Waste in DR Congo

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Abstract: Addressing climate change involves mitigation (reducing emissions) and adaptation (preparing for unavoidable consequences). Our study focuses on the waste sector in DR Congo, which is characterized by an increase in emissions attributable to 1) the evacuation of solid waste of all kinds generated by households, communities and businesses and 2) the discharge of domestic wastewater. The paper proposes a model of decision support system that will monitor the mitigation and adaptation strategies concerning the waste sector. Our system aims to provide a sustainable waste management that can lead to reduction of the GHG emissions. Such a system can help stakeholders to be efficient in their mission.

Key-Words: Waste sector, Mitigation, Adaptation, Decision support system
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1 Introduction

Climate change has been identified as a leading human and environmental crisis of the 21st century. The problem of understanding climate change (or global warming) is one of the major challenges confronting African people, their governments and the African Union (AU), [1].
The forests of the DRC sequester daily around 24.5 Gigatons of greenhouse gases, 3/4 of which are concentrated on 43% of the country's surface area. Its eatlands constitute a natural stock of more than 30 Gigatons of carbon dioxide, the equivalent of more than two years of global emissions of Greenhouse Gases, [2]. Furthermore, with its forests, water and mineral resources, the Democratic Republic of Congo is a genuine Solution Country to the climate crisis.
However, it is stated in [3] that climate change is expected to increase current vulnerabilities within the Democratic Republic of the Congo (DRC). While there will be significant biophysical impact, particularly in the northeast, with increasing temperatures and changing rainfall patterns, due to its widespread poverty, high population density, and the country's conflict situation, DRC's high vulnerability is primarily related to socioeconomic factors.
Addressing climate change involves mitigation (reducing emissions) and adaptation (preparing for unavoidable consequences), [4]. Both are multifaceted issues.
Our study focuses on the waste sector in DR Congo, which is characterized by an increase in emissions attributable to 1) the evacuation of solid waste of all kinds generated by households, communities and businesses (shops, industries, construction, agricultural residues, etc.) and 2) the discharge of domestic wastewater.
We attempt to contribute to this challenge by proposing modelling climate change and sustainability in the tropical environment specifically in DR Congo. This will help stakeholders to be involved with efficiency in their mission.
The document discusses a model that will lead to decision support for mitigation and adaptation measures in the waste sector.
Our system aims to provide a sustainable waste management that can lead to reduction of the GHG emissions and can respond to recommendations of the Sustainable Development Goals.

2 Methods

2.1 Problematic

Climate, physical phenomena and component of the natural environment, is one the principal elements of our study. Our study focuses on the tropical climate zone.

As indicated in [5] the authors point out that the tropical climate zone occupies 40% of the surface of the Earth and is located between the tropics of Cancer (latitude 23.5°N) and Capricorn (latitude 23.5°S).

Nowadays, the massive environmental changes of humanity in the Anthropocene have fundamentally affected all natural environments: including from climate change, biodiversity loss and pollution from plastic and other chemicals in the air and water, [6].

And the global environmental climate change is caused by the following components: Electricity systems, Transportation, Buildings and cities, Industries, Farm & forests.

2.2. Study area: Waste Generation and Management in DR Congo

Increases in population, economic growth and rapid urbanization, especially in developing countries, have led to increased waste production, [7].

Worldwide, waste generated per person per day averages 0.74 kilogram but ranges widely, from 0.11 to 4.54 kilograms, [8].

In Democratic Republic of Congo (DR Congo), as everywhere else, waste management encompasses the collection, transport, treatment, recovery or disposal of waste, usually those resulting from human activities. This management aims to reduce their effects on human and environmental health and the living environment.

State institutions involved in environmental issues are to varying degrees in the waste management process.

The Ministry of Environment and Sustainable Development defines policy and strategy in the sanitation sector through the development of a national sanitation plan, [9].

In particular, Kinshasa is the capital and largest city of the Democratic Republic of Congo (DRC) as well as Africa.

Following the calamitous management of waste (solid and liquid), Kinshasa city only ensures the collection and evacuation of waste on rare occasions and this constitutes aggravating factors for the degradation of the environment, [10].

2.4. Data Collection, Processing and Analysis

2.4.1. Data Collection

Three sources of data were used: the review of the documentation available in public administration and on the Internet, observation and the interview.

2.4.2. Data Processing

In this paper, we focus particularly on two categories of the waste sector, namely:

- Solid Waste Disposal Sites (SWDS) and
- Domestic wastewater (DWW).

Thus, we only describe the calculation of theses 2 waste sectors as presented in the IPCC, [11, 12]:

2.4.2.1. Calculation of emissions from Solid Waste Disposal Sites

$$CH_4 \text{ Emissions}_T = (CH_4 \text{ generated}_T - R_T) * (1 - OX_T) \quad (1)$$

where: T = inventory year; R_T = recovered CH4 in year T, Gg; OX_T = oxidation factor in year T, Gg;

$$CH_4 \text{ generated}_T = DDOCm_{\text{ decompT}} * F * 16/12 \quad (2)$$

where: CH_4 generated_T = amount of CH4 generated from decomposable material, Gg; $DDOCm_{\text{ decompT}}$ = DDOCm decomposed in year T, Gg; F = fraction of CH_4 by volume, in generated landfill gas (fraction); 16/12 = molecular weight ratio CH_4/C.

$$DDOCm_{\text{ decompT}} = DDOCm\ a_{T-1} * (1 - \exp(-k)) \quad (3)$$

where: DDOCm a_{T-1} = DDOCm accumulated in the SWDS at the end of year (T-1), Gg; k = methane generation rate constant.

$$DDOCm\ a_T = DDCOmd_T + (DDCOm\ a_{T-1} * \exp(-k)) \quad (4)$$

where: DDOCm a_T = DDOCm accumulated in the SWDS at the end of year T, Gg; $DDOCmd_T$ = DDOCm deposited into the SWDS in year T, Gg; K = methane generation rate constant.

$$DDOCm = W * DOC * DOC_f * MCF \quad (5)$$

where: DDOCm = mass of decomposable DOC deposited, Gg; W = mass of waste deposited, Gg; DOC = degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste; DOC_f = fraction of DOC that can decompose (fraction); MCF = CH_4 correction factor for aerobic decomposition in the year of deposition.

2.4.2.2. Calculation of emissions from domestic wastewater

1° Total CH4 emissions from domestic wastewater treatment and discharge

$$CH_4 \text{ Emissions} = \sum_j [CH_4 \text{ Emissions}_j] * [10^{-6}] \quad (6)$$

Where: *CH_4 Emissions* = CH_4 emissions in inventory year, kg CH_4/yr; *CH_4 Emissions $_j$* = CH_4 emissions from treatment/discharge pathway or system, j, in inventory year, kg CH_4/yr; j = each treatment/discharge pathway or system; 10^{-6} = conversion of kg to Gg.

2° Total $N_2O_{\text{ DOM}}$ = N_2O Plants $_{\text{DOM}}$ + N_2O Effluent $_{\text{DOM}}$

$$\text{Total } N_2O_{DOM} = \left(\left[\sum_{i,j}\left(U_i * T_{i,j} * EF_j\right)\right] * TN_{DOM} * \frac{44}{28}\right) + \left(\left(\left(\sum_j\left[\left(TN_{DOM} * T_j\right) * \left(1 - N_{REM,j}\right)\right)\right) * \left(EF_{Effluent} * \frac{44}{48}\right)\right) \quad (7)$$

where: Domestic *N_2O Plants* $_{DOM}$ = N_2O emissions from wastewater treatment plants in inventory year, kg N_2O/yr; *TN_{DOM}* = total nitrogen in domestic wastewater in inventory year, kg N/yr; U_i = fraction of population in income group i in inventory year; T_{ij} = degree of utilization of treatment/discharge pathway or system j, for each income group fraction i in inventory year; *I* = income group : rural, urban high income and urban low income; *J* = each treatment /discharge pathway or system; EF_j = emission factor for treatment/discharge pathway or system j, kg N2O-N/kg N; *44/28*= the conversion of kg N_2O-N into kg N_2O; $N_2O_{Effluent,DOM}$ = N_2O emissions from domestic wastewater effluent in inventory year, kg N_2O/yr; $N_{Effluent,DOM}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr; $EF_{Effluent,DOM}$ = emission factor for N_2O emissions from wastewater discharged to aquatic system, kg N_2O-N/kg N; *TN_{DOM}* = total nitrogen in domestic wastewater in the inventory year, *kg N/yr*; T_j = degree of utilisation of treatment system *j* in inventory year *($\sum T_{ij}$)*; *J* = each wastewater treatment type used in inventory year; $N_{REM,j}$ = fraction of total wastewater nitrogen removed during wastewater treatment per treatment type *j*.

2.5. Decision Support System

Decision support processes need to take account of the values and goals of stakeholders, evolving scientific information, and perceptions of risk. Decisions about how to address climate change can be complex, and responses will require a combination of adaptation and mitigation actions. Decision-makers whether individuals, public officials, or others may need help integrating scientific information into adaptation and mitigation decisions, [13].

2.6. Mitigation and Adaptation

Climate actions have often fallen into one of two strategies: mitigation efforts to lower or remove greenhouse gas emissions from the atmosphere, and adaptation efforts to adjust systems and societies to withstand the impacts of climate change, [14].

The DRC is committed to a combined unconditional and conditional contribution of up to 21% reduction in total GHG emissions compared to the BAU in 2030 (19% conditional and 2% unconditional) equivalent to an estimated level of mitigation up to 650 Mt CO2e by 2030, [15].

3 Modelling Decision Support System

3.1. Framework of the System

There are 3 basics elements in our system, namely:
- Interface for interaction homo-machine,
- Data and knowledge,
- Model of Decision (criteria and decision context).

3.2. Functional Model of Decision Support

Our decision support system for the mitigation and adaptation of greenhouse effects will be based on a series of mathematical functions. All these mathematical entities are software agents designed to act according to defined objectives.

In the following lines, the functionality model is presented and it provides an overview of the system.

Definition 1: Software Agents (SA)

In [16] the Software Agents are defined as a set of computational entities that exists in the form of a set of programs or components and that runs on the dedicated server and can interact with external components. Theirs operate flexibly and rationally in a variety of environmental circumstances, given the information it has in memory. Theirs act with minimal intervention of humans. They can require special and punctual collaboration with other embedded agents in pursuing their goals and executing tasks. *SA* are defined as the following:

$$SA: \langle \zeta, \kappa \rangle \quad (8)$$

where ζ is a set of programs and code components, *K* is a dataset and a knowledge base.

Definition 2: Code Component

Code component can be activities, services and applications, may act both as callers and as callees. It is a set of actions that performs the code component.

A code component ζ is defined by the equation function:

$$\zeta_{(m_j,a_i)} = \sum(\varphi, k, v) \quad (9)$$

where ζ are components that act as SA, φ actions perform in ζ; κ represents the knowledge base used by ζ when it is processing data through φ and ν is the set of input values concerning a particular risk. ζ returns information regarding mitigation and adaptation strategies.

Definition 4: Multi-attribute decision

The SA pursue goals or carry out tasks in order to meet their design objectives. The main objectives related to the SA which acts in the mitigation and adaptation strategies concerning the waste sector are to provide interaction mechanisms with stakeholders, policy-makers and researchers.

Let us consider that a decision matrix, [17], can enable multi-attribute decision-making, [18].

Consequently the equation function (9) becomes:

$$\zeta_{(}m_j,a_{i)} = \sum((\varphi,k,v).d) \quad (10)$$

where *d* is the decision.

The functional decision is expressed as:

$$d_{(}c_k, w_{l)} = (m_j, a_i) \quad (11)$$

where *c* is a criteria and *w* is weighted.

We call criteria *c* a set of elements $c_k(k = 1,..., n)$ defined in *d* and which takes totally orders of actions such as mitigation or adaptation. These actions represent the preferences of the decision maker according to a point of view expressed by a weight *w*. The weighted, used as an indicator, gives the importance of the actions to take Thus, *d* is the evaluation of an action m_j or a_i according to the criterion c_k.

3.3. Knowledge Base Management

The SA is used as a knowledge base for decision making to manage the risks.

Definition 5: Knowledge Base

Let the knowledge base be a construct of information, data and associations, related to different strategies of mitigation and adaptation that can be generated and derived by reasoning methods or set of decisions.

Let *k* be a set of knowledge and m_j and a_i are the key subsets;

$$k: 2^{(m,a)} \rightarrow D, \text{ many-to-one relation;}$$

$$D= \{s_1, s_2, \ldots, s_n\},$$

$$s_n \in D$$

where *D* is a set containing the sector of activities s_n; m_j is the mitigation and a_i is the adaptation. The binary element 2 expresses the construction of knowledge in a many-to-one relationship where the subset mitigation or adaptation refers to a specific sector of activity.

3.4. Interpretation

There are 3 basics components in our system, namely:

- Interface for interaction homo-machine,
- Data and knowledge,
- Model of Decision (criteria and decision context).

From an implementation point of view, we have the following configuration:

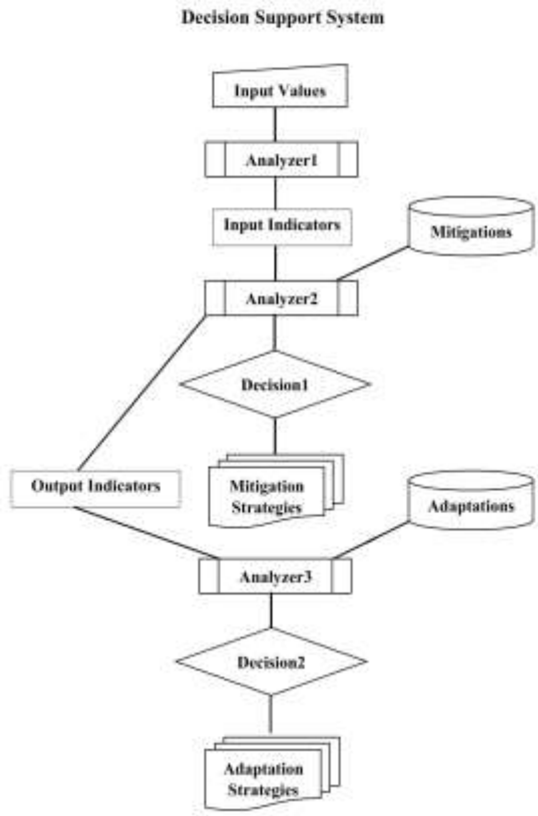

Fig. 1. Functional diagram of DSS

Let's see what the diagram means. The input values come from data collected monthly and annually on emissions from Solid Waste Disposal Sites (SWDS) from municipal solid waste (MSW) and industrial. Emission measurements involve multiple calculations which are summarized in subsection 2.4.2. Data processing.

These data are analyzed to identify input indicators. These input indicators serve as decision-making criteria to determine in the database information relating to the mitigations which will be the subject of the strategies to be adopted.

The continuous process is led to the specification of so-called output indicators which constitute values of decisional criteria for determining in the database information relating to the attenuations which will be the subject of the adaptation strategies to be taken.

3.4.1. Mitigation Strategies

Let us now consider the methane generated by the Solid Waste Disposal Sites (SWDS) from municipal solid waste (MSW) and industrial.

Table 1. Matrix of Solid Waste Disposal Sites

Year XXXX	**Value**	**Indicator**
Population (Million)	v_1	w_1
CH_4 generated$_T$ (Gg)	v_2	w_2
DDOCm $_{decompT}$ (Gg)	v_3	w_3
DDOCm a_T (Gg)	v_4	w_4
DDOCm (Gg)	v_5	w_5
CH_4 Emissions $_T$ (Gg) (Methane Emission)	V_6	W_6

The analysis of the matrix above will generate a list of indicators or weights associated with each input value.

Table 2. Matrix of Mitigation Strategies

Input Indicator	**Mitigation**	**Output Indicator**
Associate indicator (vw_j)	List of mitigation in knowledge base (m_i)	Associate indicator (mw_j)

The decisional computation of the matrix above will generate a list of mitigation strategies.

3.4.2. Adaptation Strategies

Table 3. Matrix of Adaptation Strategies

Output Indicator	**Adaptation Strategies**
Associate indicator (mw_j)	List of adaptation in knowledge base (a_i)

The decisional computation of the matrix above will generate a list of adaptation strategies.

4 Conclusion

In general, an effective response to the current and future risks from the waste sector in DR Congo require a portfolio of different types of actions, ranging from those intended to manage and reduce risk.

In this study, we wanted to understand the problem by the mathematical formalization which resulted in a model. It goes without saying that our next step will focus on simulating the system with data relating to the waste sector.

Our contribution in this article is based on the methodology of problem solving.

The purpose of our research project is to implement a decision support system, of course online, for waste management in DR Congo.

References:

[1] Tadesse D., The impact of climate change in Africa, *Institute for Security Studies, Paper 220*, 2010. Published online: https://www.files.ethz.ch/isn/136704/PAPER220.pdf

[2] Bazaïba M. E., COP 26 GLASGOW / UNITED KINGDOM, *Democratic Republic of the Congo, Country Solution to Climate Change*. 2021. Published online: https://medd.gouv.cd/wp-content/uploads/2022/07/magazine_COP_env_anglais1.pdf

[3] Ministry of Foreign Affairs of the Netherlands, Climate Change Profile: Democratic Republic of the Congo (East), *Government of the Netherlands*, 2018. Published online: https://reliefweb.int/report/democratic-republic-congo/climate-change-profile-democratic-republic-congo-east

[4] Rolnick D., Donti P. L., Kaack L. H., Kochanski K., Lacoste A., Sankaran K., Ross A. S., Milojevic-Dupont N., Jaques N., Waldman-Brown A., Luccioni A. S., Maharaj T., Sherwin E. D., Mukkavilli S. K., Kording K. P., Gomes C. P., Ng A. Y., Hassabis D., Platt J. C., Creutzig F., Chayes J., Bengio Y., Tackling Climate Change with Machine Learning. *ACM Comput. Surv.* 55, 2, Article 42, 2022, pp, 96.

[5] Val A.L., Almeida-Val V.M.F., Randall D.J., Tropical Environment, *In book: The Physiology of Tropical Fishes - Fish Physiology, Elsevier*. Vol. 21, 2006, pp.1-45.

[6] Meka E. Z., Tropical Forests and Climate Change - Report. *International Tropical Timber Organization (ITTO)*. 2008.

[7] Njoku N., Lamond J., Everett G., Manu P., An overview of municipal solid waste management in developing and developed economies: Analysis of practices and contributions to urban flooding in Sub-Saharan Africa. *Paper presented at 12th International Postgraduate Research Conference Proceedings*, 2015. Published on line: https://www.researchgate.net/publication/279868600

[8] Kaza S., Yao L., Bhada-Tata P., Van Woerden F., What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Published online: https://openknowledge.worldbank.org/bitstream/handle/10986/30317/211329ov.pdf

[9] Deputy Prime Minister's Office, Ministry of the Environment and Sustainable Development,

DR Congo, National Adaptation Plan to Climate Change (2022-2026), *United Nations Development Programme*, 2021. Published online: https://unfccc.int/sites/default/files/resource/DRC-NAP_EN.pdf

[10] Mindele U.L., Caractérisation et test de traitement des déchets ménagers et des boues de vidange par voie anaérobie et compostage pour la ville de Kinshasa. *Thèse de doctorat, Département des sciences et gestion de l'environnement, université de liège*, 2015-2016. p.1, 2016.

[11] IPCC, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change (IPCC), 2022. Published online: https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

[12] IPCC, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Waste, Vol. 5, 2021. Published online: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.html

[13] Moss, R., Scarlett P. L., Kenney M. A., Kunreuther H., Lempert R., Manning J., Williams B. K., Boyd J. W., Cloyd E. T., Kaatz L., Patton L., Ch. 26: Decision Support: Connecting Science, Risk Perception, and Decisions. Climate Change Impacts in the United States: The Third National Climate Assessment & Global Change Research Program. 620-647, 2014.

[14] Suarez I., Strategies that Achieve Climate Mitigation and Adaptation Simultaneously. *World Resources Institute*. 2022. Published online: https://www.wri.org/insights/5-strategies-achieve-climate-mitigation-and-adaptation-simultaneously

[15] Ministère de l'Environnement et Développement Durable, Contribution Déterminée à l'échelle Nationale révisée, *Vice-Primature, RD Congo*, 2021. Published online : https://unfccc.int/sites/default/files/NDC/2022-06/CDN Revisée de la RDC.pdf

[16] Muteba A. E., Modeling Software Agents: Web-Based Decision Support System for Malaria Diagnosis and Therapy, *Journal of Health Informatics in Africa*, Vol. 3, No 1, 2015.

[17] Hahn W.J., Seaman S.L., Bikel R., Making Decisions with Multiple Attributes: A Case in Sustainability Planning, *Graziadio Business Review*, Vol. 15(2), 2012. Published online: https://gbr.pepperdine.edu/2012/08/making-decisions-with-multiple-attributes-a-case-in-sustainability-planning/

[18] Borissova D., A Multi-criteria Group Decision Making Model for Selection of Green Building Project, *In book: Advances in Building Information Modeling*, 2020, pp.137-146.