A multi-dimensional framework for designing results-based energy sector resilience plans

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Abstract
Significant impacts of climate change on the energy sector in Sub-Saharan Africa could lead to this sector configurations marked by energy services supply alteration, energy services quality reduction and energy services access degradation. Such configurations of the energy sector are factors that could reduce resilience options for economic and social sectors. In the context of sub-Saharan Africa, energy sector resilience to climate change should be a crucial component of overall resilience to climate change. In practice, it will require the development of specific knowledge bodies and decision-making tools for the design, planning, management, monitoring and evaluation of the energy sector resilience policies which concern energy services supply, energy services quality, energy services demand and energy services access.
The main output of this article is the Badolo EnergyResilienceProspect framework. It is a scientific tool for the formulation, implementation, monitoring and evaluation of energy sector resilience to climate change policies based on resilience configurations that secure energy services supply, energy services quality and energy services access.
Basically, the Badolo EnergyResilienceProspect framework is an innovative scientific tool to improve the efficiency and impact of energy resilience to climate change policies. It suggests results-based energy resilience policies, taking into account contextual specificities, gender issues, social inclusion and greenhouse gas emissions reduction.

Key words: energy, climate change, resilience, planning, frameworks

1.Introduction

Significant impacts of climate change on the energy sector in sub-Saharan Africa could lead to this sector configurations marked by energy services supply alteration, energy services quality reduction and energy services access degradation [1-5]. Such configurations of the energy sector are factors that could reduce resilience options for economic and social sectors [6 -9]. In the context of sub-Saharan Africa, energy sector resilience to climate change should be a crucial component of overall resilience to climate change. In practice, it will require the development of specific knowledge bodies and decision-making tools for the design, planning, management, monitoring and evaluation of the energy sector resilience policies which concern energy services supply, energy services quality, energy services demand and energy services access. These energy sector resilience policies should be low-carbon and integrate contextual specificities, gender issues and social inclusion. [10 -12].

In this article, we propose the Badolo EnergyResilienceProspect framework, a scientific tool for energy sector resilience to climate change. It uses ClimResilience scientific framework methodological tools, concepts and decision support tools to develop an inclusive and participatory scheme for energy sector results- based policies formulation, implementation, monitoring and evaluation [13]. It includes specific climate change impacts, vulnerability factors, vulnerability indicators and resilience solutions families for the improvement of the scientific bases of energy sector resilience to climate change policies. The energy sector resilience trajectories of the Badolo EnergyResilienceProspect framework are results-based trajectories resulting from climate change impact classes. They achieve energy sector resilience configurations that secure energy services supply, energy services quality and energy services access.

Basically, the Badolo EnergyResilienceProspect framework is an innovative scientific tool to improve the efficiency and impact of energy sector climate change resilience policies. It suggests results-based energy sector resilience policies, taking into account contextual specificities, gender issues, social inclusion and greenhouse gas emissions reduction.

2. Methodology

The Badolo EnergyResilienceProspect framework uses the methodological tools and resilience scheme of the ClimResilience scientific framework to develop information families for the formulation of energy sector resilience to climate change trajectories [13]. The dimensions of the energy sector considered are the components of the vector e (e1, e2, e3, e4):

- e1= energy services supply;
- e2= energy services quality;
- e3= energy services demand;
- e4= energy services access.

The Badolo EnergyResilienceProspect framework information families are climate change impacts, vulnerability factors, vulnerability indicators and resilience solutions climatic families.

3. Results

3.1. Climate change impacts

The Badolo EnergyResilienceProspect framework Climate change impacts on the energy sector dimensions e1, e2, e3 and e4 are respectively de1, de2, de3 and de4:

- **de1**, energy services supply alteration, energy services supply development challenges intensification, energy services supply development achievements reduction, energy services supply development prospects alteration, energy services supply financing alteration, of for the of energy services supply infrastructure deficiencies amplification, energy services supply governance difficulties amplification;
- **de2**, energy services quality alteration, energy services quality development challenges intensification, energy services quality development achievements reduction, energy services quality development prospects alteration, energy services quality financing alteration, of for the of energy services quality infrastructure deficiencies amplification, energy services quality governance difficulties amplification;
- **de3**, energy services demand management alteration, energy services demand management development challenges intensification, energy services demand management development achievements reduction,

energy services demand management development prospects alteration, energy services demand management financing alteration, energy services demand management infrastructure deficiencies amplification, energy services demand management governance difficulties amplification;

- **de4**, energy services access alteration, energy services access development challenges intensification, energy services access development achievements reduction, energy services access development prospects alteration, energy services access financing alteration, of for the of energy services access infrastructure deficiencies amplification, energy services access governance difficulties amplification.

3.2. Climate change vulnerability factors

The Badolo EnergyResilienceProspect framework climate change vulnerability factors of the energy sector dimensions e1, e2, e3 and e4 are respectively ve1, ve2, ve3 and ve4:

- **ve1,** energy sources sensitivity to climate risks, deficiencies in integrating climate risks into energy services supply management plans, deficiencies in integrating climate risks into energy services supply development plans, deficiencies in integrating climate risks into energy services supply development achievements management plans, deficiencies in integrating climate risks into energy services supply development prospects management plans, deficiencies in integrating climate risks into energy services supply financing plans, deficiencies in integrating climate risks into energy services supply infrastructure management plans, deficiencies in integrating climate risks into energy services supply governance ;

- **ve2,** sensitivity of energy sources to climate risks, deficiencies in integrating climate risks into energy services quality management plans, deficiencies in integrating climate risks into energy services quality development plans, deficiencies in integrating climate risks into energy services quality development achievements management plans, deficiencies in integrating climate risks into energy services quality development prospects management plans, deficiencies in integrating climate risks into energy services quality financing plans, deficiencies in integrating climate risks into energy services quality infrastructure management plans, deficiencies in integrating climate risks into energy services quality governance;

- **ve3,** sensitivity of energy sources to climate risks, deficiencies in integrating climate risks into energy services demand management plans, deficiencies in integrating climate risks into energy services demand management development plans, deficiencies in integrating climate risks into energy services demand management development achievements plans, deficiencies in integrating climate risks into energy services demand management development prospects plans, energy services demand management financing plans, deficiencies in integrating climate risks into energy services demand management infrastructure plans, deficiencies in integrating climate risks into energy services demand management governance;

- **ve4,** energy sources sensitivity to climate risks, deficiencies in integrating climate risks into energy services access management plans, deficiencies in integrating climate risks into energy services access development plans, deficiencies in integrating climate risks into energy services access development achievements management plans, deficiencies in integrating climate risks into energy services access development prospects management plans, deficiencies in integrating climate risks into energy services access financing plans, deficiencies in integrating climate risks into energy services access infrastructure management plans, deficiencies in integrating climate risks into energy services access governance.

3.3. Climate change vulnerability indicators

The Badolo EnergyResilienceProspect framework climate change vulnerability indicators of the energy sector dimensions e1, e2, e3 and e4 are respectively ive1, ive2, ive3 and ive4:

- **ive1,** part of energy services supply concerned by energy sources sensitivity to climate risks, part of energy services supply concerned by deficiencies in integrating climate risks into energy services supply management plans, part of energy services supply concerned by deficiencies in integrating climate risks into energy services supply development plans, part of energy services supply concerned by deficiencies in integrating climate risks into energy services supply development achievements management plans, part of energy services supply concerned by deficiencies in integrating climate risks into energy services supply development prospects management plans, part of energy services supply concerned by deficiencies in integrating climate risks into energy services supply financing plans, part of energy

services supply concerned by deficiencies in integrating climate risks into energy services supply infrastructure management plans, part of energy services supply concerned by deficiencies in integrating climate risks into energy services supply governance ;

- **ive2,** part of the population concerned by an altered energy services quality due to energy sources sensitivity to climate risks, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality management plans, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality development plans, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality development achievements management plans, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality development prospects management plans, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality financing plans, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality infrastructure management plans, part of the population concerned by an altered energy services quality due to deficiencies in integrating climate risks into energy services quality governance;

- **ive3,** part of energy services demand concerned by energy sources sensitivity to climate risks, part of energy services demand concerned by deficiencies in integrating climate risks into energy services demand management plans, part of energy services demand concerned by deficiencies in integrating climate risks into energy services demand management development plans, part of energy services demand concerned by deficiencies in integrating climate risks into energy services demand management development achievements plans, part of energy services demand concerned by deficiencies in integrating climate risks into energy services demand management development prospects plans, energy services demand management financing plans, part of energy services demand concerned by deficiencies in integrating climate risks into energy services demand management infrastructure plans, part of energy services demand concerned by deficiencies in integrating climate risks into energy services demand management governance;

- **ive4,** part of the population with access to energy services concerned by energy sources sensitivity to climate risks, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access management plans, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access development plans, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access development achievements management plans, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access development prospects management plans, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access financing plans, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access infrastructure management plans, part of the population with access to energy services concerned by deficiencies in integrating climate risks into energy services access governance.

3.4. Climate change resilience solutions

The Badolo EnergyResilienceProspect framework climate change resilience solutions of the energy sector dimensions e1, e2, e3 and e4 are respectively ze1, ze2, ze3 and ze4:

- **ze1,** family of inclusive and low-carbon solutions to reduce energy sources sensitivity to climate risks, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services supply management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services supply development plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services supply development achievements management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services supply development prospects management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services supply financing plans, family of inclusive and low-carbon solutions to reduce

deficiencies in integrating climate risks into energy services supply infrastructure management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services supply governance;

- **ze2,** family of inclusive and low-carbon solutions to reduce energy sources sensitivity to climate risks, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality development plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality development achievements management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality development prospects management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality financing plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality infrastructure management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services quality governance;

- **ze3,** family of inclusive and low-carbon solutions to reduce energy sources sensitivity to climate risks, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services demand management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services demand management development plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services demand management development achievements plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services demand management development prospects plans, energy services demand management financing plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services demand management infrastructure plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services demand management governance;

- **ze4,** family of inclusive and low-carbon solutions to reduce energy sources sensitivity to climate risks, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access development plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access development achievements management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access development prospects management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access financing plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access infrastructure management plans, family of inclusive and low-carbon solutions to reduce deficiencies in integrating climate risks into energy services access governance.

3.5. Climate change resilience trajectories

The Badolo EnergyResilienceProspect framework includes three resilience trajectory segments: the short-term resilience trajectory segment (h1), the medium-term resilience trajectory segment (h2) and the long-term resilience trajectory segment (h3). Table 1 specifies the families of information associated with the resilience trajectories segments.

Table 1: Families of information associated with the resilience trajectories segments

Energy sector resilience trajectories segments	Partial resilience configurations	Climate change impact classes to mitigate	Families of vulnerability factors to reduce	Families of resilience solutions to implement	Families of vulnerability indicators
Short term resilience trajectory segment	ẽh1	đẽh1 = Fh1(de1, de2, de3, de4)	vđẽh1	zđẽh1	ivđẽh1
Medium term Resilience trajectory segment	ẽh2	đẽh2 = Fh2(de1, de2, de3, de4)	vđẽh2	zđẽh2	ivđẽh2
Long term resilience trajectory segment	ẽh3	đẽh3 = Fh3(de1, de2, de3, de4)	vđẽh3	zđẽh3	ivđẽh3

In table 1:

- đẽhi (i = 1, 2, 3) is the climate change impacts class to mitigate. It includes impacts from the families of climate change impacts de1, de2, de2, de3 and de4;
- vđẽhi (i = 1, 2, 3) is the subset of vulnerability factors to be addressed to mitigate climate change impacts under đẽhi;
- zđẽhi (i = 1, 2, 3) is the subset of resilience solutions to be implemented to reduce climate change vulnerability factors under vđẽhi;
- ivđẽhi (i = 1, 2, 3) is the subset of vulnerability indicators to monitor the evolution of vulnerability under vđẽhi reduction.

4. Discussion

The design, management, monitoring and evaluation of energy sector climate change resilience policies requires several types of knowledge bodies and decision support tools. They should be robust, contextual, multidimensional and integrate gender issues, social inclusion and greenhouse gas emissions reduction. They concern change impacts, vulnerability factors, resilience solutions and resilience trajectories. The knowledge bodies and decision support tools of the Badolo EnergyResilienceProspect framework meet the criteria of relevance and robustness for energy sector resilience policies. They consider several dimensions of the energy sector, are contextual and designed to underpin results-based resilience policies. Climate change impacts families integrate energy sector management, development achievements and prospects, financing and the governance. Vulnerability factors families include energy sector characteristics and contextual situations to be addressed to mitigate climate change impacts.

Knowledge and decision support tools for energy sector resilience policies are addressed by several scientific publications [14-24]. The Badolo EnergyResilienceProspect framework increases the knowledge for managing the threats posed by climate change to the energy sector and proposes novel approaches to accelerate the realization of energy sector resilience configurations.

The Badolo EnergyResilienceProspect framework includes several innovations for energy sector resilience policies to climate change. They result specifically from the implementation of the concepts of climate change indirect impacts, residual impacts, residual vulnerabilities, classes of impacts, resilience trajectories segments and resilience configurations. The resilience trajectories of the Badolo EnergyResilienceProspect framework achieve energy sector resilience configurations that secure energy services supply, energy services quality and energy services access. Such a situation of securing energy services is the marker of energy sector climate change resilience policies efficiency.

5. Conclusion

The objective of this article was energy services resilience to climate change in Sub-Saharan Africa context.
The main result of this article is The Badolo EnergyResilienceProspect framework which includes several innovations for energy sector resilience to climate change policies. They result specifically from the implementation of the concepts of climate change indirect impacts, residual impacts, residual vulnerability, classes of impacts, resilience trajectories segments and resilience configurations. The resilience trajectories of the Badolo EnergyResilienceProspect framework achieve energy sector resilience configurations that secure energy services supply, energy services quality and energy services access. Such a situation of securing energy services is the marker of energy sector climate change resilience policies efficiency
Basically, the Badolo EnergyResilienceProspect framework is an innovative scientific tool to improve the efficiency and impact of energy resilience to climate change policies. It suggests results-based energy resilience policies, taking into account contextual specificities, gender issues, social inclusion and greenhouse gas emissions reduction.

Conflicts of interest
The author declares no financial or non-financial conflicts of interest
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References

1. Biqing Xie, Bibo Xie, Assessing the impact of climate policy on energy security in developed economies, International Review of Economics & Finance, Volume 90,2024, Pages 265-282. https://doi.org/10.1016/j.iref.2023.11.006.

2. Cronin, J., Anandarajah, G. & Dessens, O. Climate change impacts on the energy system: a review of trends and gaps. Climatic Change 151, 79–93, 2018. https://doi.org/10.1007/s10584-018-2265-4

3. Juan-Carlos Ciscar, Paul Dowling, Integrated assessment of climate impacts and adaptation in the energy sector, Energy Economics, Volume 46,2014, Pages 531-538.

4. Roberto Schaeffer, Alexandre Salem Szklo, André Frossard Pereira de Lucena, Bruno Soares Moreira Cesar Borba, Larissa Pinheiro Pupo Nogueira, Fernanda Pereira Fleming, Alberto Troccoli, Mike Harrison, Mohammed Sadeck Boulahya, Energy sector vulnerability to climate change: A review, Energy, Volume 38, Issue 1,2012, Pages 1-12. https://doi.org/10.1016/j.energy.2011.11.056

5. Vahid M. Nik, A.T.D. Perera, The Importance of Developing Climate-Resilient Pathways for Energy Transition and Climate Change Adaptation, One Earth, Volume 3, Issue 4,2020, Pages 423-424. https://doi.org/10.1016/j.oneear.2020.09.013

6. Meltem Ucal, George Xydis, Multidirectional Relationship between Energy Resources, Climate Changes and Sustainable Development: Technoeconomic Analysis, Sustainable Cities and Society, Volume 60, 2020,102210. https://doi.org/10.1016/j.scs.2020.102210

7. Xunzhang Pan, Tianming Shao, Xinzhu Zheng, Yanru Zhang, Xueqing Ma, Qi Zhang, Energy and sustainable development nexus: A review, Energy Strategy Reviews, Volume 47,2023,101078. https://doi.org/10.1016/j.esr.2023.101078.

8. Gricelda Herrera-Franco, Harry Alberto Bollmann, Janaina Camile Pasqual Lofhagen, Lady Bravo-Montero, Paúl Carrión-Mero, Approach on water-energy-food (WEF) nexus and climate change: A tool in decision-making processes, Environmental Development, Volume 46,2023, 100858. https://doi.org/10.1016/j.envdev.2023.100858

9. Philbert Mperejekumana, Lei Shen, Shuai Zhong, Fabien Muhirwa, Mohamed S. Gaballah, Jean Marie Vianney Nsigayehe, Integrating climate change adaptation into water-energy-food-environment nexus for sustainable development in East African Community, Journal of Cleaner Production, Volume 434,2024,140026. https://doi.org/10.1016/j.jclepro.2023.140026.

10. Davide, M.; De Cian, E.; Bernigaud, A. Building a Framework to Understand the Energy Needs of Adaptation. Sustainability 2019, 11, 4085. https://doi.org/10.3390/su11154085

11. Somayeh Ahmadi, Amir Hossein Fakehi Khorasani, Ali Vakili, Yadollah Saboohi, Georgios Tsatsaronis, Developing an innovating optimization framework for enhancing the long-term energy system resilience against climate change disruptive events, Energy Strategy Reviews, Volume 40, 2022,100820. https://doi.org/10.1016/j.esr.2022.100820

12. Saeid Charani Shandiz, Greg Foliente, Behzad Rismanchi, Amanda Wachtel, Robert F. Jeffers, Resilience framework and metrics for energy master planning of communities, Energy, Volume 203,2020,117856. https://doi.org/10.1016/j.energy.2020.117856

13. Mathieu BADOLO. ClimResilience, a global climate resilience framework, Research Square. https://doi.org/10.21203/rs.3.rs-3942168/v1

14. Sam C.A. Nierop, envisioning resilient electrical infrastructure: A policy framework for incorporating future climate change into electricity sector planning, Environmental Science & Policy, Volume 40,2014, Pages 78-84. https://doi.org/10.1016/j.envsci.2014.04.011

15. Mir Sayed Shah Danish, Mohammed Elsayed Lotfy Elsayed, Mikaeel Ahmadi, Tomonobu Senjyu, Hedayatullah Karimy, Hameedullah Zaheb, A strategic-integrated approach for sustainable energy deployment, Energy Reports, Volume 6, Supplement 2,2020, Pages 40-44. https://doi.org/10.1016/j.egyr.2019.11.039

16. IEA (2015), Making the energy sector more resilient to climate change, IEA, Paris https://www.iea.org/reports/making-the-energy-sector-more-resilient-to-climate-change

17. S. Roostaie, N. Nawari, C.J. Kibert, Integrated sustainability and resilience assessment framework: From theory to practice, Journal of Cleaner Production, Volume 232,2019, Pages 1158-1166. https://doi.org/10.1016/j.jclepro.2019.05.382

18. Shardul Tiwari, Chelsea Schelly, Ge Ou, Mostafa Sahraei-Ardakani, Jianli Chen, Fatemeh Jafarishiadeh, Conceptualizing resilience: An energy services approach, Energy Research & Social Science, Volume 94,2022,102878. https://doi.org/10.1016/j.erss.2022.102878

19. Wenrui Fan, Zanxin Wang, Wanqing Lv, Effects of the resilience of energy systems on economic sustainability, Sustainable Production and Consumption, Volume 41,2023, Pages 379-390. https://doi.org/10.1016/j.spc.2023.08.019

20. Paul E. Roege, Zachary A. Collier, James Mancillas, John A. McDonagh, Igor Linkov, Metrics for energy resilience, Energy Policy, Volume 72,2014, Pages 249-256. https://doi.org/10.1016/j.enpol.2014.04.012.

21. Yanling Lin, Zhaohong Bie, Study on the Resilience of the Integrated Energy System, Energy Procedia, Volume 103,2016, Pages 171-176. https://doi.org/10.1016/j.egypro.2016.11.268

22. Sam C.A. Nierop, envisioning resilient electrical infrastructure: A policy framework for incorporating future climate change into electricity sector planning, Environmental Science & Policy, Volume 40, 2014, Pages 78-84. https://doi.org/10.1016/j.envsci.2014.04.011

23. Luigi Aldieri, Andrea Gatto, Concetto Paolo Vinci, Evaluation of energy resilience and adaptation policies: An energy efficiency analysis, Energy Policy, Volume 57,2021,112505. https://doi.org/10.1016/j.enpol.2021.112505

24. Somayeh Ahmadi, Yadollah Saboohi, Ali Vakili, Frameworks, quantitative indicators, characters, and modeling approaches to analysis of energy system resilience: A review, Renewable and Sustainable Energy Reviews, Volume 144,2021,110988. https://doi.org/10.1016/j.rser.2021.110988