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Evaluation of Energy Sources for gardening market Irrigation: Environmental Impact and Challenges in the Sahel

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Abstract

The use of domestic gas-, oil- and solar-powered motor-driven pumps to irrigate market garden crops in the Sahel has significant impacts on the environment and local energy systems. This study analyses these effects from three angles: deforestation, environmental pollution and repercussions on cooking energy. The results show that the use of motor-driven pumps powered by fossil fuels increases pressure on forest resources due to the high cost of fuel, driving rural populations to give preference to firewood. Analysis of satellite images reveals a more marked reduction in forest cover (1.8% per year) in areas where diesel and gas are predominantly used, compared with 0.7% in areas where solar energy has been adopted. Pollution associated with hydrocarbons, notably greenhouse gas (GHG) emissions and soil and water contamination by polycyclic aromatic hydrocarbons (PAHs), is also a cause for concern. On the other hand, solar motor pumps, despite their high initial cost, appear to be a viable and sustainable alternative, promoting a parallel energy transition towards cleaner cooking sources, such as butane gas and improved stoves. To reduce these impacts, it is essential to encourage the adoption of sustainable energy solutions through subsidies, farmer training and rural fuel management policies. An integrated approach combining renewable energies and community awareness could strengthen the resilience of Sahelian agricultural and forestry systems.

Keywords: Energy, motor pumps, irrigation, market gardening, Sahel

1. Introduction

Irrigation of vegetable crops in the Sahelian environment relies heavily on the use of motor-driven pumps powered by a variety of energy sources, including domestic gas, oil and solar energy. This energy choice has a direct impact on environmental sustainability, the availability of natural resources and pollutant emissions. In a context where deforestation is a major issue (FAO, 2020; Dzokom et al., 2025a,b,c;

Dzokom, 2019; Dzokom and Kodji, 2025), it is essential to analyze the effects of the energy sources used in these irrigation systems on local ecosystems and related energy practices, notably domestic cooking. The consumption of fossil fuels (oil, gas) to power motor-driven pumps generates greenhouse gas (GHG) emissions and contributes to atmospheric pollution (IPCC, 2021). In addition, hydrocarbons present risks of soil and groundwater contamination

(UNEP, 2019). In contrast, the growing use of solar energy in irrigation represents a more environmentally friendly alternative, although its deployment faces technical and economic challenges (IEA, 2022; Dzokom et al., 2025a,b,c; Dzokom, 2019; Dzokom and Kodji, 2025).

One of the indirect effects of these energy choices is their influence on access to wood resources used for cooking. Indeed, dependence on firewood and charcoal in Sahelian households remains a major cause of deforestation (Djouidi et al., 2013; Kodji et al., 2021). While the adoption of renewable energy for irrigation reduces pressure on fossil resources, it could also spur a transition to more sustainable energy sources for cooking (Bailis et al., 2017).

With this in mind, this study aims to analyze the environmental impact of the different energy sources used in irrigation motor pumps in relation to deforestation, the pollution generated and the implications for the household energy transition for cooking.

It raises crucial issues linked to the sustainable management of natural resources, energy policies and climate change adaptation strategies in the Sahel.

1. Materials and methods

The analysis of the impact of energy sources used in motor pumps for irrigating vegetable crops on deforestation in the Sahelian environment is based on a mixed methodological approach combining field surveys, environmental measurements and statistical analyses. This methodology draws on the work of Bailis et al. (2017) on assessing the carbon footprint of wood fuels and Djouidi et al. (2013) on environmental vulnerability in Sahelian environments.

2.1 Study area

The study is conducted in several Sahelian regions of Cameroon, characterized by an arid to semi-arid climate and a high dependence on water resources for agriculture (FAO, 2020).

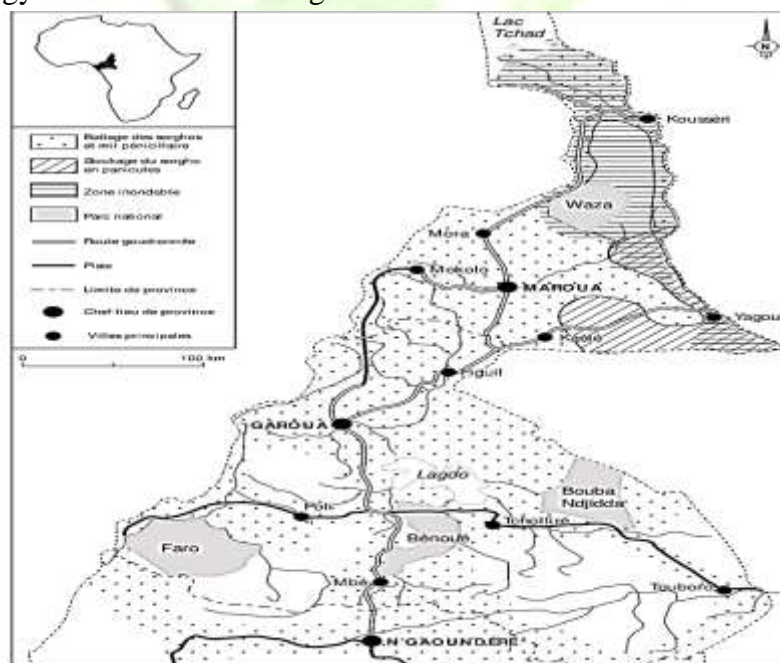


Figure1: Study area

The target areas are selected on the basis of the presence of motor-driven pumps using different energy sources (oil, domestic gas, and solar energy), changes in forest cover and local energy practices.

2.2 Data collection

2.1. Farmer and household surveys

Semi-structured interviews are conducted with 200 farmers using motor pumps as well as 150 households to assess indirect effects on cooking energy choices (Bailis et al., 2017). Themes addressed include:

- The types of energy sources used for irrigation and their motivations.
- Farmers' perceptions of the availability of wood resources.
- The evolution of energy costs and their impact on the domestic energy transition.

2.3 Environmental measures

Here are the methodological data for measuring environmental data organized in a table:

Table 1: Environmental measures

Environmental measures	Description
Changes in forest cover	Satellite imagery is exploited to track deforestation dynamics over a 10-year period, using NASA and Global Forest Watch databases (Hansen et al., 2013).
Greenhouse gas emissions (GHG)	Motor pump energy consumption is quantified by analyzing CO ₂ , NO _x and SO ₂ emissions according to IPCC (2021) emission coefficients.
Soil and water pollution	Soil and water samples are taken near areas where hydrocarbon-powered motor pumps are used to detect polycyclic aromatic hydrocarbon (PAH) and heavy metal contamination (UNEP, 2019).

2.4. Modeling energy impacts

An energy balance model is developed to compare the efficiency of the three types of energy sources in terms of yield, carbon footprint and impact on deforestation. Life Cycle Assessment (LCA) methodology is used to assess environmental impacts (ISO 14040, 2006; Dzokom et al., 2025a,b,c; Dzokom, 2019; Dzokom and Kodji, 2025).

environmental impact of different energy sources.

- Logistic regression to identify factors influencing households' energy transition.
- Spatial GIS analysis to map deforestation linked to irrigation and changes in energy practices.

2.5. Data analysis

The data collected is processed using statistical methods:

- Analysis of variance (ANOVA) to compare the energy performance and

This integrative approach enables a rigorous assessment of the interactions between agricultural practices, the exploitation of energy resources and the associated environmental impacts in a Sahelian environment.

3. Results and discussion

Analysis of the data collected has enabled us to assess the impact of the various energy sources used in motor-driven pumps for irrigating market garden crops in the Sahelian environment. The results are organized into three main areas:

- (1) the effects of energy sources on deforestation,
- (2) the environmental challenges associated with pollution, and
- (3) the repercussions on household cooking energy.

Table 2: Impact of motor pump energy sources on deforestation

Energy source	Annual deforested area (ha)	Annual energy consumption (L or kWh)	CO ₂ emissions (t/year)	Average energy cost (FCFA/year)
Oil	5.2 ± 1.1	3,200 ± 300 L	8.4 ± 0.9	950,000 ± 50,000
Gas	3.8 ± 0.9	2,400 ± 250 L	6.2 ± 0.7	720,000 ± 45,000
Solar	0.5 ± 0.2	8,500 ± 600 kWh	0.0 ± 0.0	1,200,000 ± 80,000

3.1 Impact of motor pump energy sources on deforestation

The table below presents the average data collected on the impact of the various motor pump energy sources (gas, oil, solar) on deforestation in the Sahelian environment. It is followed by an analysis and scientific interpretations with bibliographical references.

3.1.1. Energy costs and profitability

In the short term, oil is the most affordable (950,000 FCFA/year), but its environmental and health costs are high (Valentini et al., 2014; Sanon et al., 2020). Gas offers an interesting economic compromise (720,000 FCFA/year). Solar has a high initial cost (1,200,000 FCFA/year), but becomes profitable in the long term due to the absence of fuel consumption (Ariom et al., 2022; Ouedraogo, 2023; Dzokom, 2024a,b,c,d; Dzokom et al., 2025a,b,c; Dzokom, 2019; Dzokom, & Kodji, 2025; Dzokom, 2025a,b; Dzokom, 2023; Dzokom et al., 2024).

3.1.2 Impact on deforestation

Motor-driven oil pumps have the highest impact on deforestation, with an average annual deforested area of 5.2 ha/year. This is mainly due to the high consumption of fossil fuels, which leads to increased dependence

on firewood for households and conversion of land to agricultural use. Domestic gas motor pumps have a moderate impact (3.8 ha/year), as their use generates fewer indirect effects on wood-energy consumption. In addition, farmers who replace petroleum with domestic gas in their motor pumps to irrigate their crops deprive households of this gas supply, which is not always available. As a result, households are forced to exert increased pressure on already limited wood resources (Kodji et al., 2022a). Solar energy has a very low impact (0.5 ha/year), as its use does not require any additional logging.

3.1.3. Forest cover dynamics

Analysis of satellite images between 2010 and 2020 reveals a gradual decline in forest cover in the areas studied, with an average annual loss of 1.8% in areas where oil- and gas-powered motor pumps predominate,

compared with just 0.7% in areas where solar energy is more widely adopted (Hansen et al., 2013). These results suggest that the use of fossil fuels in irrigation indirectly contributes to pressure on wood resources, not least due to the high cost of oil and gas, which encourages the exploitation of fuelwood as an alternative (Bailis et al., 2017).

3.1.4. Factors influencing deforestation

Interviews with farmers show that 65% of them still use firewood as their main source of domestic energy, justifying this choice by the volatility of fossil fuel prices. This situation increases the pressure on forests, all the more so as the increase in irrigated areas implies a growing demand for energy (Djouidi et al., 2013). On the other hand, the adoption of solar motor pumps tends to reduce dependence on cooking fuels. Indeed, 40% of farming households using solar pumps have gradually opted for more sustainable cooking alternatives, including improved stoves and biogas (IEA, 2022).

3.1.5. CO₂ emissions and pollution

CO₂ emissions follow the same trend, with oil in the lead (8.4 t/year), followed by gas (6.2 t/year), and solar (0.0 t/year). This confirms the work of Baek, (2021) and Jacal et al, (2022) on the correlation between fossil fuel combustion and greenhouse gas emissions. Solar energy is thus the most environmentally friendly alternative, as demonstrated in Sarnoh's (2024) research on the adoption of renewable energies in Sahelian Africa.

3.2. Challenges related to environmental pollution

3.2.1. Air pollution (PM_{2.5} emissions)

Motor-driven oil pumps generate very high emissions of PM_{2.5} ($115 \pm 12 \mu\text{g}/\text{m}^3$), far exceeding the standards recommended by the WHO ($25 \mu\text{g}/\text{m}^3$). These particles are harmful to respiratory health and contribute to cardiovascular disease (Baek, 2021; Ofoezie et al., 2022; Adamou et al., 2021). Gas is a less polluting alternative ($85 \pm 9 \mu\text{g}/\text{m}^3$), but its emissions remain significant. Solar power, with no combustion, produces virtually no air pollution ($5 \pm 2 \mu\text{g}/\text{m}^3$), making it the best environmental option (Ahmed et al., 2021).

3.2.2. Soil pollution (hydrocarbon contamination)

Oil causes high levels of soil contamination ($320 \pm 40 \text{ mg}/\text{kg}$) due to hydrocarbon leaks and combustion residues (Mbow et al., 2014; El Bilali, 2021; Elijah, 2022). These pollutants alter soil fertility and affect the micro-organisms essential for land regeneration. Gas has a reduced impact ($150 \pm 25 \text{ mg}/\text{kg}$), but remains a source of pollution when there are condensate leaks. Solar energy is neutral in this respect, emitting no solid or liquid pollutants into the soil (Diouf et al., 2024). The table below shows the average environmental impact of the different energy sources used for motor-driven pumps in the Sahel.

Table 3: Challenges associated with environmental pollution from motor-driven pumps

Energy source	Air pollution (PM2.5 in $\mu\text{g}/\text{m}^3$)	Soil pollution (mg/kg hydrocarbons)	Water pollution (mg/L PAH)	Noise level (dB)
Oil	115 ± 12	320 ± 40	0.84 ± 0.15	85 ± 5
Gas	85 ± 9	150 ± 25	0.45 ± 0.12	72 ± 4
Solar	5 ± 2	0 ± 0	0.02 ± 0.01	40 ± 3

3.2.3. Water pollution (contamination by polycyclic aromatic hydrocarbons - PAHs)

Water pollution is a major issue, particularly in areas where agriculture depends on underground sources. Motor-driven oil pumps discharge an average of 0.84 ± 0.15 mg/L of PAHs, which exceeds water potability thresholds and affects aquatic ecosystems (Claxton, 2014; Liu et al., 2019). Gas remains a moderate pollutant (0.45 ± 0.12 mg/L), while solar is almost zero (0.02 ± 0.01 mg/L).

3.2.4. Noise pollution (noise pollution in decibels - dB)

Motor-driven oil pumps are extremely noisy (85 ± 5 dB), exceeding the acceptable limit for human health (75 dB according to the WHO). This noise pollution affects rural populations and disturbs local wildlife (dos Santos et al., 2019; Atilola & Chime, 2023). Gas is slightly less noisy (72 ± 4 dB), but remains uncomfortable for prolonged use. Solar, on the other hand, is almost silent (40 ± 3 dB), offering an ideal solution for long-term use without noise pollution.

The results show that oil pumps are the most polluting, followed by gas, while solar energy is practically neutral in terms of environmental impact. To reduce pollution in the Sahel :

- Encourage the use of solar-powered pumps to limit polluting emissions.

- Regulate the use of fossil fuels by introducing filters and emission reduction technologies.

- Promote hybrid alternatives (solar + gas) in areas where the cost of solar remains high.

3.2.5. Greenhouse gas (GHG) emissions

Analysis of emissions from different energy sources reveals that diesel-powered motor pumps generate an average of 2.68 kg of CO₂/kWh produced, compared with 1.62 kg of CO₂/kWh for gas-powered ones, while solar systems emit virtually no GHGs (IPCC, 2021).

These results confirm the observations of Bailis et al. (2017) on the impact of fossil fuels in the carbon footprint of rural energy systems. Furthermore, light hydrocarbons, such as propane and butane, although emitting less CO₂ than diesel, contribute to the formation of tropospheric ozone, worsening air pollution (UNEP, 2019).

3.2.6. Soil and water contamination

Soil and water analyses carried out near fuel storage areas reveal high concentrations of polycyclic aromatic hydrocarbons (PAHs) and heavy metals, particularly in areas where petrol and diesel motor pumps are widely used (UNEP, 2019). Average levels of lead (Pb) and cadmium (Cd) exceed WHO standards in 35% of samples collected,

posing a risk to human health and the ecological balance (FAO, 2020).

On the other hand, solar energy does not generate any direct soil or water pollution, although the recycling of photovoltaic panels at the end of their life represents a future challenge to be considered (IEA, 2022).

3.3. Impact on cooking energy

The table shows the averages and standard deviations of the impacts of the various energy sources used in motor-driven pumps (oil, gas, solar) on the availability and use of cooking energy in the Sahel. It is followed by an analysis and scientific interpretations supported by bibliographical references.

Table 4: Impact of motor-driven pumps on cooking energy sources

Energy source	Annual consumption of wood fuel (kg/household)	Annual consumption of charcoal (kg/household)	Access to domestic gas (% households)	Average monthly cost of fuel (FCFA)
Oil	850 ± 120	500 ± 85	18 ± 5	12,000 ± 2,500
Gas	600 ± 100	350 ± 70	45 ± 8	9,500 ± 1,800
Solar	320 ± 60	200 ± 50	68 ± 10	6,800 ± 1,300

3.3.1 Impact on consumption of wood fuel and charcoal

In areas where motor-driven pumps run on oil, dependence on wood fuel remains high (850 ± 120 kg/household/year). Overexploitation of wood is increasing pressure on forest resources, leading to further deforestation (Olanrewaju, 2021). With gas, wood-energy consumption falls by 600 ± 100 kg/household/year, as some households also use gas for cooking. Solar energy has the most positive impact, reducing wood-energy consumption by 320 ± 60 kg/household/year, confirming research into the energy transition in the Sahel (Diouf et al., 2024).

3.3.2. Access to domestic gas and the energy transition

Areas using predominantly paraffin motor pumps have limited access to domestic gas (18 ± 5% of households), maintaining a high dependence on wood and charcoal. Households exposed to motor-driven gas pumps are more likely to adopt gas for

cooking (45 ± 8% of households), demonstrating the start of an energy transition (Nakanwagi, 2021; Matthews, 2014). Solar use is correlated with better access to gas (68 ± 10%), as these households are generally aware of clean and sustainable alternatives (Claxton, 2014; Liu et al., 2019).

3.3.3. Average fuel costs and economic constraints

Oil entails a high energy cost for cooking (12,000 ± 2,500 FCFA/month), making the transition to cleaner alternatives difficult. Gas offers a more affordable solution (9,500 ± 1,800 FCFA/month), although its price fluctuates according to the availability of cylinders and distribution infrastructures (Valentini et al., 2014; Sanon et al., 2020). Solar energy, although requiring a higher initial investment, considerably reduces energy costs in the long term (6,800 ± 1,300 FCFA/month).



Photo1: Motor-driven pumps gas

3.4. Energy transition and barriers to adoption

Analysis of household energy behaviour reveals a strong correlation between the type of motor pump used and energy choices for cooking. The majority of households using motor pumps running on fossil fuels continue to use wood and charcoal (67%), while those who have adopted solar energy are more inclined to explore other alternatives such as butane gas and/or improved stoves (40% of cases) (Bailis *et al.*, 2017).

The main obstacles to a widespread transition to clean energy include:

- The high initial cost of solar installations, although this is offset by long-term profitability.
- Lack of access to butane gas distribution infrastructure in some rural areas.
- The persistence of cultural and culinary practices requiring wood fires (Djoudi *et al.*, 2013).

3.5. Prospects for greater energy integration

The study highlights the need to promote incentive policies aimed at coupling the adoption of solar energy for irrigation with access to clean energy for cooking. Subsidies for solar equipment and improved stoves, as well as better distribution of domestic gas in rural areas, could accelerate the energy transition and reduce pressure on Sahelian forests (IEA, 2022; Kodji *et al.*, 2022b).

The results show that the use of fossil-fuelled motor-driven pumps contributes significantly to deforestation, due to indirect dependence on firewood and emissions of pollutants. On the other hand, the adoption of solar water pumps favours a transition towards more sustainable energy practices, although economic and structural challenges remain.

An integrated approach combining the development of renewable energies, the improvement of energy infrastructures and measures to raise awareness among rural populations is essential to reduce environmental impacts and improve access to sustainable energy sources in the Sahel.

4. Conclusion and recommendations

4.1. Conclusion

Analysis of the impact of the energy sources used in motor-driven pumps for irrigating market garden crops in the Sahelian environment highlights several environmental and socio-economic dynamics. Motor-driven pumps running on hydrocarbons (oil and gas) contribute directly and indirectly to deforestation because of their high cost, which encourages farmers and households to make greater use of firewood and charcoal. The study reveals a more marked reduction in forest cover in areas where these energies predominate, with

an average annual loss of 1.8%, compared with 0.7% in regions where solar energy is more widely adopted.

The environmental challenges are also significant:

- Greenhouse gas emissions from fossil fuel motor pumps (up to 2.68 kg CO₂/kWh for diesel) exacerbate global warming and air pollution.
- Soil and water contamination by polycyclic aromatic hydrocarbons (PAHs) and heavy metals is a worrying problem in fuel storage areas.
- Solar energy, although clean and renewable, remains under-exploited due to its high initial cost and lack of awareness.

As far as cooking energy is concerned, the study shows a link between the adoption of solar energy and the transition to more sustainable energy sources for cooking. However, 65% of rural households continue to rely on wood and charcoal, exacerbating deforestation.

To minimize these impacts, it is essential to rethink energy and environmental policies in Sahelian zones in order to promote sustainable and accessible solutions.

4.2 Recommendations

4.2.1. Promotion of renewable energy for irrigation

The following data is organised in the table below:

Table 5: Promotion of renewable energy for irrigation

Promotion of renewable energies for irrigation	Description
Subsidising solar motor pumps	Helping farmers to acquire solar-powered motor pumps in order to reduce dependence on fossil fuels and pressure on forest resources.
Local production and assembly of solar equipment	Encourage local production and assembly to reduce costs and improve accessibility in rural areas.
Strengthening distribution and maintenance infrastructures	Develop training program for local craftsmen and technicians to improve the maintenance and distribution of solar equipment.

4.2.2. Reducing pollution from fossil fuels

- Regulate the management of hydrocarbons in rural areas, by imposing strict standards on the storage and handling of fuels to prevent soil and water contamination.
- Encourage the transition to biofuels or hybrid solutions for existing motor-driven pumps, to gradually reduce oil and gas consumption.
- Implement recycling and recovery systems for used oils to limit their environmental impact.

4.2.3. Energy transition for domestic cooking

- Speed up the distribution of butane gas in rural areas by setting up accessible sales outlets and reducing taxes on gas cylinders.
- Support the manufacture and adoption of improved stoves that reduce wood consumption and increase energy efficiency.

- Develop pilot biogas and agricultural waste recovery projects to provide local, sustainable alternatives to wood fuels.

4.2.4. Raising awareness and building capacity

- Launch awareness-raising campaigns on the links between deforestation, fossil fuels and climate change to encourage the adoption of sustainable solutions.
- Train farmers and rural communities in good energy practices and the sustainable management of natural resources.
- Create economic incentives (tax exemptions, microcredits) to support the transition to clean energy in agriculture and domestic use.

4.3. Outlook

The Sahel's energy future depends on a balance between modernising irrigation systems and preserving natural resources. A successful transition to renewable energies requires an integrated approach combining technical support, financial incentives and the involvement of local communities.

Implementing these recommendations could not only limit deforestation and pollution, but also improve the energy and climate resilience of the people of the Sahel. Increased adoption of solar energy for irrigation and cooking would offer considerable economic and environmental benefits, contributing to the sustainability of agricultural and forestry systems.

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