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Arab Academy for Science, Technology, and Maritime Transport, AASTMT Abu Kir Campus, Alexandria, EGYPT
P.O. Box: Miami 1029
Tel: (+203) 5622366/88 – EXT 1069 and (+203) 5611818
Fax: (+203) 5611818
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A Scoping Review of Adopter Attributes, Motivations, and Barriers of Solar Home Systems Adoption: Lessons for Sub-Saharan Africa

Tiyamike Ngonda[1]

Department of Mechanical and Mechatronic Enginering, Cape Peninsula University of Technology, Cape Town, South Africa

ngondat@cput.ac.za

ABSTRACT

The diffusion of solar home systems in sub-Saharan Africa would reduce the prevalent energy poverty in the region. However, the adoption of solar home systems faces significant barriers that have hampered the adoption process. This paper presents a scoping review that investigates non-institutional factors influencing the Solar Home Systems diffusion process. The study searched three databases, Scopus, ScienceDirect and Web of Science, for conference papers and journal articles that focused on barriers and motivations for adopting solar home systems. The search produced 116 records. After applying the exclusion criteria, 14 papers were included in the thematic analysis. The analysis revealed that affordability and inadequate information on solar home systems are significant barriers to adoption. The analysis further showed that solar home system adopters, typically highly skilled and educated high-income individuals, are motivated by the peer effect, energy security and independence, monetary saving and desire to protect the environment. Finally, the findings suggest that government intervention is essential for the widespread diffusion of solar home systems in sub-Saharan Africa.

Index Terms: barriers, diffusion, motivations, photovoltaic, solar home systems, sub-Saharan Africa

I. INTRODUCTION

Most governments in sub-Saharan Africa (SSA) struggle to provide their populations with access to affordable and clean energy, one of the United Nations' 17 Sustainable Development Goals [1]. One of the forms of clean energy whose usage has grown globally over the past two decades is solar photovoltaic (PV). Solar PV generation has seen rapid increases, reaching 821 Terawatt-hours in 2020, 3.1% of global electricity generation [2]. Most of this increase has been from China, the United States and Europe. The gains were driven by policy interventions such as subsidy-driven deployment, tax credits and feed-in metering [2]. In the absence of similar interventions, Africa has lagged in generating electricity from renewable sources and access to electricity [3]. At 20% in 33 of the 49 SSA countries, the region has the lowest electricity access in the world [4].

In addition to access, SSA suffers from low-quality electricity supply, as evidenced by the frequent electricity shortage problems, often resulting in unannounced load shedding to keep grids from instability [5], [6]. This frequent load shedding has forced middle-class households in SSA to self-generate electricity using diesel generators, thereby contributing to CO2 emissions. This approach is not sustainable. It does not consider the renewable energy sources available in the African continent. Instead, a more sustainable system would be electricity micro-generation using solar thermal, solar photovoltaics, and heat pumps which would be exploited if reliance on fossil fuels is to be reduced [7].

However, Africa's electricity generation from renewables is increasing slowly, only growing by 6% between 1985 and 2020 [3]. The contribution of solar generation is even more minor, only 2.23% as of 2020, despite having excellent conditions for PV electricity [3], [8]. SSA's long term daily power output achievable by PV exceeds 4.5 kilowatt-hours per installed kilowatt peak (kWh/kWp) [8]. As the continent with the lowest

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access to electricity, this high PV electricity potential suggests potential in SSA for future growth of solar home systems (SHS) installations. SHS are solar PV systems that are used in the microgeneration of electricity in individual houses. They could contribute to energy security and autonomy by reducing dependency on the grid [9]–[13]. In addition, SHS installations could mitigate climate by reducing the dependence on biomass for cooking. The use of biomass for cooking and water heating contributes to deforestation and emissions of CO2 [14].

Unlike China, the United States and European countries, most African countries cannot solely depend on institutional level financial incentive approach to fasten SHS adoption. This scoping review investigates non-institutional factors influencing the SHS diffusion process. It builds on a previous review of SHS in SSA [15] by focusing on household-level factors influencing SHS adoption, particularly those relevant to SSA. The findings and recommendations would assist policymakers, academics, and other energy stakeholders in SSA to develop interventions that would promote the adoption of residential SHS. In addition, increasing SHS installations is crucial for SSA countries to ease the pressure on their electricity grids and provide access to off-grid communities.

II METHODOLGY

This scoping review followed the five-step framework developed by Arksey and O'Malley [16].

A. *Step 1: Identifying the Research Question*

The following question guided this scoping review of the barriers and enablers of the adoption of SHS: What household-level factors facilitate or constrain the adoption of SHS?

B. *Step 2: Identifying Relevant Studies*

The author searched the three databases, Scopus, ScienceDirect and Web of Science. The searches were performed on 24 November 2021 and targeted the fields, title, abstract, and keywords. The author used search string (*Solar photovoltaic OR PV*) AND (*residential OR home OR domestic*) AND (*barriers OR enablers*) AND (*ownership OR adoption*).

C. *Step 3: Study Selection*

The scoping review included all conference papers and journal articles published up to November 2021. The scope of the review encompassed literature focussing on the barriers and enablers of the adoption of SHS. This included articles focusing on electricity generation from solar for cooking, lighting, and other domestic electricity usage. All records were selected without a time limit.

The titles and abstracts of the records were screened to exclude those that fit the exclusion criteria. The study excluded literature that was not published in English, which focused on policy, commercial electricity users, community solar projects or solar PV as part of microgrids. Also, literature focusing on post-installation issues such as payback period and installed system efficiency was removed. Finally, after eliminating duplicates and initial screening, the full texts were imported in Mendeley reference manager for eligibility screening and to streamline the review process.

The screening process is summarised in Figure 1, and fourteen publications were considered relevant for inclusion in the analysis.

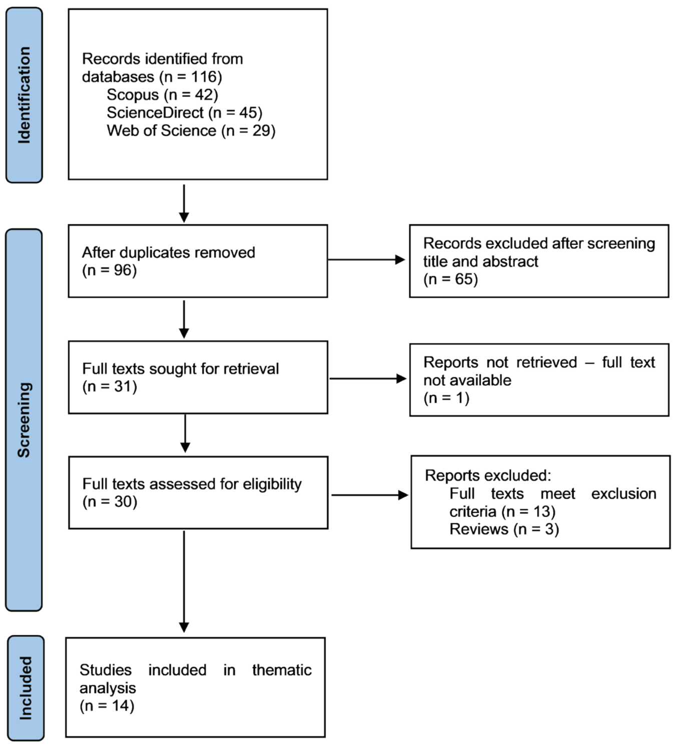

Fig. 1. Modified PRISMA flow diagram illustration of the study screening process.

D. *Step 4: Data Charting Process*

The included studies were imported into NVivo for thematic synthesis and analysis.
Study characteristics, including the publication type, setting, year, were input as file classifications and attributes in NVivo to facilitate data display and comparison. The author performed the data extraction, and a peer reviewer audited the process for confirmability.

The thematic synthesis comprised three concurrent flows of activity: (1) data condensation through coding, (2) data display through charts, maps and diagrams and (3) theme development and verification [17]. This process was conducted by the author and audited by a peer reviewer.

E. *Step 5: Summarising Results*

The results are reported according to PRISMA guidelines extension for scoping review [18].

III. RESULTS

The searches returned 116 journal papers and conference papers, 42 in Scopus, 45 in ScienceDirect, and 29 in the Web of Science. Table I summarises the characteristics of the studies included in the scoping review.

Most of the reviewed studies were conducted in United States (n = 4), the remaining in Sweden (n = 2), Pakistan (n =2), Australia (n = 1), Finland (n = 1), New Zealand (n = 1), Vietnam (n = 1), United Kingdom (n = 1) and Nigeria (n = 1). The earliest was conducted in 2013, and the highest number was three studies in 2017, 2019 and 2020. There was one each in 2014 and 2018, two in 2016 and no studies in 2015 and 2021.The synthesis included a thematic analysis process that uncovered four themes: household attributes that influence SHS adoption, household-level barriers to SHS adoption, motivations for SHS adoption and outcomes of SHS adoption. The themes and their subthemes are presented in Table II, and their overviews are presented in the following sections.

TABLE I
SYNTHESIS OF INCLUDED STUDIE

First author, date, reference	Country	Purpose	Sample and data collection	Methods	Relevant/main findings
Balcombe et al., 2014, [7]	United Kingdom	- To identify the motivations and barriers associated with adopting microgeneration. - To determine the relative weight of each factor. - To identify policy interventions that would be implemented and the corresponding target population.	Sample: SHS adopters, considerers and rejectors: - 291 respondents to an online survey - 12 participants for semi-structured interviews	Mixed methods: - Quantitative analysis of online survey results - Qualitative analysis of semi-structured interviews	- SHS adopters are motivated by energy security – protection from future increases and independence from power companies. - SHS adopters think they save money from utility bills/earn money from the feed-in tariffs. - High initial costs are a barrier to SHS adoption. - Insufficient information is a barrier to SHS adoption.
Do et al., 2020, [19]	Vietnam	- To find the drivers of the initial boom in SHS adoption in Vietnam. - To identify potential barriers to future expansion. - To identify approaches that facilitate future expansion.	Sample: government agencies and departments, non-governmental organisations, multilateral partners, universities and research entities: - 46 interviews - Five focus groups - Documents	Mixed method – inductive approach: - Qualitative analysis of interview and focus group data. - Qualitative and quantitative analysis of documents.	- Enabling factor – ready market availability of PV technology and low cost due to proximity to China - Utility-scale PV faces more enormous barriers than SHS. - Barrier to SHS – high upfront costs (65% of respondents) – US$1117/kW. - Barrier to SHS – complex and cumbersome approval procedures. - A barrier to SHS – lack of technical information and assistance (46% of respondents).
Fikru, 2020, [20]	United States	- To examine household, community and county-level variables explaining energy savings of SHS adopters.	Sample: SHS adopters and considerers: - Survey – 1577 households	Quantitative analysis.	- SHS adoption influenced by electricity tariffs – higher tariffs are an incentive to adopt SHS. - Local regulations and policies influence SHS adoptions – electrical and fire codes can be barriers. - Homeowners, retirees, higher income and higher educated occupiers are more likely to adopt SHS.
Ford et al., 2017, [21]	New Zealand	- To explore factors driving PV uptake in New Zealand.	Sample: SHS adopters and stakeholders in the PV supply chain: - 18 interview participants – PV supply chain stakeholders. - 19 interviews with SHS adopters.	Theoretical framework - energy cultures framework and multi-level perspective. Qualitative analysis – thematic analysis.	- SHS adopters motivated by energy security (independence from power companies and protection from future increases). - Perceived poor ROI because of low feed-in tariffs. - Quality and access to information on PV technologies and economics influences SHS adoption. - Peer effect- seeing someone in the community adopting SHS has a positive influence on SHS adoption.

Ford et al., 2017, [21]	New Zealand	- To explore factors driving PV uptake in New Zealand.	Sample: SHS adopters and stakeholders in the PV supply chain: - 18 interview participants – PV supply chain stakeholders. - 19 interviews with SHS adopters.	Theoretical framework - energy cultures framework and multi-level perspective. Qualitative analysis – thematic analysis.	- SHS adopters motivated by energy security (independence from power companies and protection from future increases). - Perceived poor ROI because of low feed-in tariffs. - Quality and access to information on PV technologies and economics influences SHS adoption. - Peer effect- seeing someone in the community adopting SHS has a positive influence on SHS adoption.
Graziano et al., 2019, [22]	United States	- To typify SHS adopters and characterise the influence of peer effects in the PV diffusion process.	Sample: SHS adopters in four Connecticut towns – Hartford, East Hartford, Glastonbury and Manchester - Data from Census 200 and 2010 and Connecticut Energy Financial and Investment Authority (CEFIA).	Quantitative approach: - Inferential statistics and spatial modelling	- SHS adopters are typically high income and older homeowners. - Peer effects – keeping up with the Joneses – are influential in the short-range (0.5 miles). - Renters have less incentive to adopt SHS.
Karjalainen et al., 2019, [23]	Finland	- To deepen understanding of barriers faced and the experiences of early SHS adopters in Finland.	Sample - 28 owners of single-families houses (all over Finland). Data collection - 6 face-to-face interviews and 22 telephone interviews.	Qualitative analysis of interview data. - thematic analysis.	- It is possible to overcome some of the barriers to SHS adoption: - Some SHS adopters overcame inadequate knowledge by sharing knowledge and pooling resources to solicit expert advice. - Some SHS adopters reduced initial PV costs by pooling resources, buying in bulk, and self-installing SHS. - Adopters derive socio-psycho- and ideo- pleasures from using SHS. They become more aware of their energy usage.
Khalil et al., 2017, [13]	Pakistan	- To investigate the issues, including barriers, of diffusion of solar PV at the household level.	Sample – 48 households in Peshawar Pakistan – sample included 24 SHS adopters and 24 non-adopters. Data collection - semi-structured questionnaire-based interviews.	Quantitative data analysis: - descriptive statistics.	- Most respondents (74%) believe that impact of load shedding can be eliminated by using SHS. - Some people (50%) worry about battery cost and lifespan when considering adopting SHS. - There is some distrust in SHS that needs to be overcome before widespread adoption of SHS.
A. Palm, 2017, [24]	Sweden	- To deepen understanding of the underlying mechanisms behind the social influence of peers in SHS adoption,	Sample - 95 SHS adopters (65 valid responses) and 16 telephone interviews, sample not representative. Data collection – questionnaire and semi-structured interviews.	Mixed methods approach -Quantitative analysed using descriptive statistics. -Qualitative data mainly was for confirmation/explanation of qualitative data.	-Peer effects are more potent when considerers know the adopters before contact – 20% influenced (25% raised interest) by someone in their neighbourhood, 20% (22% reported an increased interest) by someone outside their community, 18% (20% reported an increased interest) by seeing SHS in their neighbourhood. -Considerers inquiries focused on SHS economic performance, technical characteristics and subsidies. -Most SHS adopters were old, youngest 49 years old and highly skilled/educated. -Adopters expressed interest in environmental issues -Peers influential in raising interest in SHS.
J. Palm & Eriksson, 2018, [25]	Sweden	- To uncover how households gather and use information about SHS and to discuss how this can be optimised.	Sample – 44 households (14 had SHS installed, 25 bought but waiting for installation). Data collection – semi-structured interviews.	Qualitative approach - Thematic analysis.	- Some non-adopters do not have sufficient information on SHS- e.g. confusing SHS with solar water heaters. - Some non-adopter worry about perceived violation of SHS to esthetics to their house. - Environmental engagement is antecedent to SHS adoption.
Qureshi et al., 2017, [12]	Pakistan	- To investigate household level issues affecting the adoption of SHS.	Sample – 36 households (9 off-grid SHS, nine on-grid SHS and 18 non-adopters) – Lahore. Data collection – interviews, semi-structured questionnaire-based interviews.	Mixed method approach – informed by Rogers' model of innovation diffusion.	- 86% of respondents cite energy security (eliminating impacts of power outages) as a driver of SHS adoption. - Most SHS adopters use other energy sources – including generators. - High initial cost and absence of financing are significant barriers to SHS adoption. - Social acceptance of SHS (peer effect) is crucial for the adoption and sustenance of SHS. - Environment concerns ranked highest among the motivators of SHS adoption.
Rai and Robinson, 2013, [26]	United States	- To study and characterise information networks associated with SHS adoption in Texas. - To uncover how potential adopters mitigate uncertainties and non-monetary costs associated with SHS adoption.	Sample – 365 SHS adopters (40% of the 922 contacted). Data collection – online survey (questionnaire).	Quantitative approach: - Descriptive statistics. - Hypothesis testing.	-The level of uncertainty about SHS adoption is reduced if SHS information is acquired from a trustworthy source. -Peer effects are not limited to the same neighbour – could be friends or family that do not stay in the same neighbourhood. -Peer effects reduce the time a considerer takes to become an adopter. -One of the underlying drivers of peer effect is the perceived trustworthiness of neighbourhood contacts, friends and family.

Rai et al., 2016, [27]	United States	- To analyse SHS adopters decision-making process with a focus on the role of the information search process in mitigating adoption barriers.	Sample - 380 completed responses (out of 2131) Data collection – survey (questionnaire).	Quantitative approach - Descriptive statistics. - Multivariate econometric modelling.	- An increase in electricity tariffs motivates SHS adoption, particularly for those approaching retirement. - It is possible to have high SHS adoption without peer effects – 53% reported no prior SHS in their neighbourhood. - Interest ins SHS adoption can be initiated by spark events such as direct marketing, an encounter with an SHS company at a retail store event. - 82% co-adopted SHS with other energy-saving products.
Ugulu and Aigbayboa, 2019, [10]	Nigeria	- To investigate the motives for SHS adoption by private consumers in urban Nigeria.	Sample – 14 SHS adopters Data collection – open-ended semi-structured interviews.	Mixed method approach – primarily qualitative with some quantitative reporting: - Thematic analysis - Descriptive statistics	- 80% of the respondents indicated that the adopted SHS to ensure reliable energy supply – Nigeria has frequent load shedding. - Slightly less than 60% were motivated by savings in utility bills.
Zander, 2020, [28]	Australia	- To assess the relative importance of barriers and motivations of those adopting SHS in Australia.	Sample – 1126 respondents from 1400 selected to participate. Data collection – online questionnaire – data collection subcontracted to an external company.	Quantitative approach: - Descriptive statistics.	- For Australian SHS adopters, reducing electricity bills (16%) was more important than avoiding future increases in electricity prices. - Contributing to the reduction of CO_2 was the 4th most crucial motivation for SHS adoption. - High initial costs and low feed-in tariffs were considered significant barriers for lower-income adopters, not so much for high-income adopters.

TABLE II
THE THEMES AND SUBTHEMES THAT EMERGED FROM THEMATIC ANALYSIS OF INCLUDED STUDIES

Theme	Subtheme
Household attributes that influence SHS adoption	Skilled, educated, older and high household income Interested in preserving the environment Energy efficiency literate Co-adoption of other renewable energy and efficiency measures
Household-level barriers to SHS adoption	Affordability - high capital investment and maintenance costs - components such as batteries Scepticism about benefits of SHS Inadequate and untrustworthy SHS information Complex administrative requirements for SHS installation
Motivations for SHS adoption	Peer effect - keeping up with the neighbours Energy security – protection against future electricity price increases Energy autonomy independence from electricity supply companies Monetary savings - save money due to reduced utility bills Environmental – help protect the environment
Outcomes of SHS adoption	**Awareness and interest in energy politics** **A better understanding of own energy usage** **Socio-, psycho- and ideo-pleasures of SHS ownership** **Energy behaviour change**

A. Household Attributes that Influence SHS Adoption

Most of the studies found that adopters shared similar attributes. They were older than average [7], [25], [27], professionally skilled or highly educated [7], [20], [23]–[25], [27], [28], had a higher household income, were energy efficiency literate [10], [21], [23], [25] and were interested in environmental issues [24], [25]. It is worth noting that there was one contrary finding on the age of adopters. An Australian study by Zander [28] found that younger people, motivated by environmental concerns, also adopt SHS.

The adopters were generally interested in environmental issues and technologies that developed over time [24], [25]. As a result, their interest was broader than SHS, covering broader renewable energy issues and politics. This broader interest was shown in their co-adoption of renewable technologies [7], [12], [20], [21], [23], [27]. They co-adopted efficient heating/cooling systems, solar thermal systems, hydro, wind turbines, battery storage, and smart thermostats. These other technologies had been adopted either prior, simultaneously or after adopting SHS. Qureshi et al. (2017) and Ugulu and Aigbayboa (2019) found a different co-adoption pattern in Pakistan and Nigeria. The SHS adopters co-adopted fossil fuel-driven power generators.

The studies suggest that adopters and rejectors have similar income and education statuses, whereas considerers have lower incomes. It is worth noting that although adopters and rejectors share several traits, J. Palm and Eriksson [25] found that rejectors had relatively lower knowledge of energy efficiency technologies. Also, rejectors had different motivations than adopters. For example, J. Palm and Eriksson [25] report that rejectors in their study were more concerned about the impact of SHS on the esthetics of their houses and of whether their neighbours would approve of SHS installations.

B. Household-level Barriers to SHS Adoption

The studies showed that households are deterred from adopting SHS by affordability - high capital investment [12], [13], [19], [21], [28] and high maintenance costs – components such as batteries need to be replaced at some intervals [12], [13], [21], [28], inadequate and untrustworthy SHS information[7], [19], [21], [23], [25], [26], scepticism about benefits of SHS[12], [21], [23], [27], [28] and complex administrative requirements for SHS installation [19], [20].

The two elements of affordability, high initial costs and the cost of batteries, are related [12]. However, it is possible to have an SHS without incorporating energy storage through batteries. Although this would reduce the initial cost of SHS, it would mean that some of the electricity generated would not be used unless there is some feed-in to the grid. Having a feed-in system when the household energy demand is lower than self-generated electricity then recouping this when household demand is high would eliminate the need for batteries. Unfortunately, this is beyond the control of households and depends on the energy policies of countries [21], [28].

With or without battery storage, there is consensus among adopters, considerers and rejectors [13] that high initial costs are the most significant barrier to SHS adoption [12]. In Zander's study [28], owners ranked high initial costs as almost two times more important than the second rated barrier. Also, Balcombe et al. [7] found that for considerers and adopters, the high initial costs were 50% more significant than any cost saving that they would make from installing SHS.

SHS adoption is also constrained by a lack of clear, impartial, and trustworthy technical and financial information on SHS viability [7]. Because of the significant initial capital investments, households want real tax incentives, feed-in tariffs and future electricity pricing estimates. However, when potential adopters have difficulty processing the available information, they become sceptical of potential financial and environmental benefits of installing SHS or prolong the period they take to move from considerer to adopter [26]. Do et al. [19] showed that households are also concerned about the lack of credible information about the quality and reliability of SHS and service providers. This is a challenge because most of the information on SHS is provided by service providers. Some studies suggest that this anxiety is reduced if the information on SHS was provided by a government entity, the utility companies or the potential adopter's peers [24]–[26].

In some cases, the barrier of the lack of credible information on SHS was accompanied by the scepticism of SHS financial benefits, often associated with the uncertainties of calculating the payback period for SHS installations [21]. In their study, Karjalainen et al. [23] reported that the payback period for SHS installations is often long, 15 to 25 years. This long payback deters older potential adopters. In addition, there are uncertainties in the estimates of payback for such long periods because the future pricing of electricity is unknown. Furthermore, Zander [28] reported that some potential adopters are sceptical of the environmental benefits of solar panels.

C. Motivations for SHS Adoption

The included studies showed that SHS adopters are motivated by the desire for energy security [7], [21], [28], energy autonomy [10], [12], [13], [21],

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[28], saving money from reduced electricity bills [10], [20], [28], environmental protection [7], [12], [23], [28] and the peer effect [12], [22]–[24], [26], [27].

The respondents in most of the cited protection from futures rise in electricity prices and protection from load shedding as critical motivators of SHS adoption. Most SHS adopters, notably those older, indicated that they needed protection against future rises in electricity prices [21]. This motivation was cited by those who had retired or were near retirement and those who became off-grid. The past rises in electricity costs informed the stance of these households. For example, one adopter from the study by Ford et al.[21] indicated that they installed SHS because electricity prices had gone up by 24% over the previous three years.

SHS adopters, particularly those in developing countries, also mentioned protection from loading shedding as a critical motivator for their adopting SHS [10], [12], [13]. In a Nigerian study by Ugulu and Aigbayboa [10], 80% of SHS adopters cited energy security in the form of reliable energy supply as the main reason they adopted SHS. These SHS adopters co-adopted power generators with SHS installations, further signalling the importance of reliable energy supply, even more, important than improving the environment. Khalil et al. [13] suggested that the co-adoption with power generators might sign of distrust in standalone SHS.

Another frequently stated motivation for adopting SHS was protecting the environment. However, the relative importance of adopting SHS to preserve the environment is unclear. For example, the study by Balcombe et al. [5] ranked protecting the environment as the fourth most crucial motivator, less important than saving or earning money. Despite this, the study found that SHS adopters were more inclined to present their SHS installation to others to indicate their environmental commitment. The study by Zander [27] ranked protecting the environment as the third overall. However, they found that it was the dominant reason among younger adopters.

Several studies suggested that some SHS adopters were influenced by their peers [12], [22], [24], [27] or by the desire to inspire others to produce clean energy [7], [23]. Graziano et al. [22] suggested that these peer effects are effective in the short range as potential adopters as vicariously influenced by their neighbour SHS installations. Also, it is efficacious for potential adopters could seek information on the quality and economics of SHS installations from people in their community other than from outsiders. Finally, A. Palm [24] extended the peer effect beyond the same neighbourhood blocks to include potential adopters' co-workers and friends.

Peer effects are essential for raising potential SHS adopters' interest and speeding the decision time between considering and adopting [22], [24], [26], [27]. A. Palm [24] categorised peer effects into active, where there is direct interpersonal contact, and passive, where there is vicarious influence. A. Palm's study [24] found that passive peer effects were less influential than active peer effects in the SHS diffusion process. As a result, they were less likely to lead to direct contact with SHS adopters. Potential adopters use direct communication to obtain and verify SHS information and confirm that SHS adoption would be a sound choice. According to Rai and Robinson [26], direct contact with SHS adopters is the single most effective strategy to spending up decision time between considering and adopting. They found that direct contact can shorten decision times by as much as 4.6 months.

D. Outcomes of SHS Adoption

Most respondents indicated that they found the potential financial return of SHS adoption challenging to establish because of uncertainties of computing the SHS payback period study [23]. However, the SHS adopters realised monthly savings in electricity bills [20]. The included studies showed that SHS adoption has other non-monetary outcomes. SHS adoption often contributes to energy behaviour change, such as using high power-consuming appliances when solar energy is available. Also, SHS adopters co-adopt other renewable energy interventions, monitor their energy consumption and purchase more efficient appliances [12], [23], [27]. Furthermore, some SHS adopters gain new awareness and interest in energy politics; SHS adopters often talk about energy policies and energy-saving technologies, thereby contributing to peer effects [23].

IV. DISCUSSION

This scoping review provides an overview of household-level factors that influence SHS diffusion that might potentially influence SHS diffusion in sub-Saharan Africa, thereby extending the work of Kezilcec and Parikh [15], a general review of SHS diffusion in sub-Saharan Africa. Although the review aims to inform policy on SHS diffusion in sub-Saharan Africa, the included studies were not geographically limited to maximise the factors that would be uncovered.

The review found that the SHS diffusion is influenced by household attributes, including income, age, and education status of potential SHS adopters. SHS adopters are motivated by monetary, environmental, energy security and independence concerns. Also, peer effects influence SHS adoption. On the other hand, affordability arising from high capital and maintenance costs was found to be a major barrier to SHS adoption. The other barriers are inadequate and untrustworthy information on SHS, the complex administrative approval process for SHS installations and scepticism about the potential benefits of SHS adoption.

A. Practical Implications for Sub-Saharan Africa

The findings suggest that government support is required for the widespread adoption of SHS in regions such as SSA because most potential adopters have low incomes and are not highly educated. Increasing SHS uptake would be the most productive way of minimising the energy poverty prevalent in SSA. For this to be done, there is a need to reduce the barriers to SHS adoption, particularly the significant barriers of affordability and availability of quality SHS information.

Minimising the affordability barrier is crucial for SHS adoption in SSA as most households cannot afford the high one-off payment for SHS [4]. Therefore, there is a need for SSA countries to develop financing systems for SHS installations. One approach is the Pay-As-You-Go (PAYG) system was tried in Kenya [29], [30]. PAYG approach eliminates the initial costs of SHS, thereby allowing homes to make payments based on their electricity. However, the disadvantage of the PAYG approach is that the household will never become owners of the SHS, thereby limiting their direct economic benefits of ownership.

Other approaches include supporting hire purchase of SHS through access to government-supported microfinancing, subsidies for purchasing SHS and generous feed-in tariffs. SHS ownership in SSA is unsustainable without government support due to payback period uncertainties and high repayment due to most banks' preference for short loan periods [4]. Short loan periods require higher repayments, making SHS financing less attractive for most SSA households who live below the poverty line. Thus, SSA governments need to subsidise or finance SHS loans to mitigate this challenge. Examples from other developing countries such as Laos and Vietnam show that if properly implemented, financing and cost recovery of SHS installations through generous feed-in tariffs could contribute to SSA's rapid electrification [4], [19].

For sustainable and rapid adoption of SHS, the challenge of the availability of clear and trustworthy information needs to be addressed [19], [21], [23], [25]. Evidence from the scoping review suggests that the barrier of inadequate information might be more potent in SSA as most people in SSA are not as educated as the participants in the included studies. A multi-sector approach to SHS information dissemination might be more appropriate to counter the barrier. Governments, SHS experts and the private sector could collaborate to provide information on various options of SHS and to champion SHS adopters. These stakeholders would also facilitate joint ordering of SHS, a proven effective strategy speeding the SHS diffusion in Finland [23].

B. Limitations and Future Research

The scoping review is not without limitations. The review inadvertently excluded other relevant literature by limiting the search to publications indexed in Scopus, ScienceDirect and Web of Science. For example, the study excluded reports from entities such as the World Bank and the International Energy Agency, which potentially contribute to the subject. In addition, the literature search was not geographically limited, and as a result, some of the nuanced contextual issues relevant to SSA might not have been captured. Therefore, this limitation needs to be addressed in future research to determine which factors highlighted in this study apply to SSA. Further, future research needs to quantify the relative importance of each of the identified factors to SSA countries. This information would facilitate more targeted interventions to fasten SHS adoption in the region.

V. CONCLUSION

The findings of this scoping review suggest that widescale diffusion of SHS cannot happen in SSA without government support. The included studies showed that a typical adopter of SHS is a highly skilled and educated high-income individual who is energy efficiency literate and environmentally cognisant. This profile is opposite to that of a typical resident of sub-Saharan Africa, indicating that it is unlikely that household driven SHS adoption would happen in SSA. The profile of residents of SSA makes the two main barriers, the affordability and information barriers, more potent. Therefore, SSA governments would need to intervene to mitigate the influence of these barriers.

The reviewed papers highlight gaps for further research. Further research is needed to uncover which factors are relevant for SSA and quantify their relative importance in the SHS adoption process. This information is essential for developing targeted interventions to mitigate the barriers and promote SHS adoption in the region. In addition, speeding up SHS adoption is crucial for eliminating energy poverty prevalent in the region. This review contributes by uncovering the factors that need to be considered in developing SHS diffusion policy.

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Integrating Renewable Energy into Nigeria's Energy Supply Mix

Nuhu Caleb Amulah

Department of Mechanical Engineering, Faculty of Engineering, University of Maiduguri, P. M. B 1069, Maiduguri, Nigeria.

amulahn@unimaid.edu.ng

ABSTRACT

In this paper, simulation model for Nigeria's energy system is developed using EnergyPLAN simulation tool to study the structure of the present energy system and explore alternative future scenarios based on renewable energy sources. First, the 2017 reference scenario was developed and validated to reflect Nigeria's energy supply and consumption in 2017. Two other future scenarios were then developed; the 2030 REMP scenario to show a pathway to achieving the Renewable Energy Master Plan target of increasing the supply of renewable electricity by 36% of the total electricity generation by 2030; and the 2050 RE scenario which seeks to increase the share of renewable energy by >70% of the total electricity generation and introduces the concept of electric vehicles and the use of biofuel in the transport sector. Both the 2030 REMP and the 2050 RE scenarios employed the National Energy Master Plan 7% reference growth scenario for all sectors using 2017 as the base year. The study shows that with the abundance of renewable energy sources in Nigeria, it is possible to develop an energy system that is sorely dependent on renewable energy. The 2030 REMP shows that the shift from fossil fuel power plant to renewable energy for electricity generation results in an increase in the share of renewable energy in electricity production from 20.2% in 2017 to 37.88% in 2030 while the 2050 RE shows that the share can go up to 71.20% if proper policies and infrastructures are put in place.

Index Terms: *electricity generation, EnergyPLAN, energy system, modelling, Nigeria*

I. INTRODUCTION

Nigeria's population is rapidly on the rise, and by 2050 Nigeria would account for 4.2% of the total world population, becoming the third most populous country only behind China and India (United Nations, Department of Economic and Social Affairs, Population Division, 2017). Population increase coupled with increase in standard of living would lead to a high demand for energy. Energy security is essential; the economic growth of a nation, as well as its progress and development largely depend on energy (Oyedepo, 2012).

Making energy more affordable, accessible, and environmentally friendly has become a major global topic when discussing energy. For no less than a century, burning fossil fuels has spawned most of the energy required to drive cars, power businesses, and keep the lights on in homes (Denchark, 2018). Even today, oil, coal and gas provide for nearly 80% of the Nigerian energy needs. This dominance is not without a price, as it is associated with environmental and climate challenges. People in Nigeria need to change their energy consumption, and they need to change the way they produce their products and plastics; they need to move away from fossil fuels and they need to do it quickly (Herder, 2019).

An increased popularity in the use of renewable energy technology is perceived as one way of meeting these challenges. A shift towards the use of renewable energy has been a key point on the policy agenda in most countries around the world. More than a few governments have made this a milestone by setting ambitious targets for the implementation of such projects. The level to which these policies have been positive varies between countries (Rolf, et al., 2007). Despites its numerous advantages, the penetration of renewable energy is still faced with barriers such as market failure, market distortion, and technical, financial, economic as well as institutional barriers (Painuly, 2001).

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First, the foremost challenge is to expand the amount of renewable energy in the supply system, particularly the electricity supply (Lund, 2007). Nigeria Renewable Master Plan (REMP) provides a roadmap for increasing the usage of renewable energy in electricity supply. The Master Plan targets to increase the contributions to the electricity supply mix from renewable energy sources (solar, wind, hydro, and biomass) by 23% of total electricity generation in 2025 and 36% in 2030 (ECN, 2005). This study is set out to develop an energy system model for Nigeria which integrates the use of renewable energy, particularly for electricity generation. Firstly, a reference model based on the year 2017 is developed and validated for accuracy. Two models for future scenarios i.e., the 2030 Renewable Energy Master Plan model (hereafter referred to as 2030 REMP) and the 2050 renewable energy scenario (referred to as 2050 RE), are then developed to highlight possible pathway to an efficient utilization of renewable energy sources in energy production. The energy scenarios are an "if-then" analysis and should not be considered as a prediction of what will happen in the future (Teske, et al., 2016).

A. Nigeria Energy Situation

Nigeria is faced with energy crisis and this has been going on for the past five decades. The consequence of this is that many industrial and commercial activities are being affected negatively. There is a significant increase in the number of households, commercial ventures, and industries that consume electricity. This is due to the rapid increase in population and development in industrial and commercial activities. As a result, the demand for electricity has outstripped the supply capacity. The Council for Renewable Energy of Nigeria reports that power outages have caused a loss of about 126 billion naira annually (CREN, 2009). Nnanna and Uzorh (2011) reported that firms spend about 25% to 40% of their initial investment on acquisition of facilities to enhance electricity supply. Aside this negative economic impact, this situation also exposes people to carbon emissions due to the frequent use of generators in different households and business enterprises.

According to the International Energy Agency (IEA) estimates (IEA, 2019), the total primary energy supply in Nigeria in 2017 was 1827.50 TWh, in which biofuel/waste had the highest share percentage (74.41%), followed by oil products (14.09%), natural gas (9.01%), crude oil (2.16%), hydro (0.30%) and coal (0.18%). The total final consumption in the same year was 1539.93 TWh. The residential, commercial and public services sectors had the largest share at 80.38%, followed by transport (13.16%), industry (5.43%) and non-energy use (1.04%). The total electricity consumption of Nigeria in 2017 was 25.77 TWh. Nigeria's power generation capacity in 2017 was 12664 MW including 10522 MW from fossil fuels, 2110 MW from hydroelectricity, and 32 MW from solar, wind, biomass and waste. About 83% of fuel mix for power generation was natural gas. For a country with such a large population, the power generated is grossly inadequate. Coupled with the population increase and increased economic activities, the power consumption is expected to radically amplify. The country is in an ominous state vis-à-vis the supply of energy. This translates into low economic growth and development. Therefore, it is pertinent to delve to renewable energy which are in abundance to plan a new future path for Nigeria.

II. METHODOLOGY

A. The EnergyPLAN Simulation Tool

There is a great difficulty in selecting an appropriate energy tool for developing future scenarios of energy system, particularly as it pertains to Nigeria. However, based on the review of 37 computer tools for analysing the integration of renewable energy into various energy systems (Connolly, et al., 2010), the EnergyPLAN simulation tool was chosen for this study. There is no dearth of literature on the use of this simulation model for energy system modelling.

The tool has been used to provide key insight and potentials for neo-carbon energy ecosystem (Abdulganiyu, 2017); to develop an energy system model which integrates all the energy production, conversion and consumption sectors (Ma, et al., 2014); to examine the role of energy storage in high renewable energy systems (Lund & Mathiesen, 2009), as well as to predict the optimization of the combination of various fluctuating renewable energy into the electricity system (Lund, 2006). EnergyPLAN has also been used to effectively analyse energy systems with high share of renewable energy for several countries including Ireland (Connolly, et al.,

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2010), Latvia (Porubova, 2010), United Kingdom (Le & Bhattacharyya, 2011), Macedonia (Ćosić, et al., 2012), Denmark (Kwon & Østergaard, 2012), Kenya and Tanzania (Abdulganiyu, 2017), etc.

The EnergyPLAN model is an input/output simulation model that simulates the performance of a given energy system in hourly steps throughout a year. It was developed purposefully for energy planning strategies on the basis of technical and economic analyses with interest on the penetration of high renewable energy mix. The inputs into the model are demands, renewable energy sources, energy plant capacities, costs and a number of optional different simulation strategies emphasising import/export and excess electricity production. The outputs are energy balances and resulting annual productions, fuel consumption, import/exports and total costs including income from the exchange of electricity (Münster & Lund, 2009; Lund & Thellufsen, 2021). A more detailed overview of the tool can be found in Lund and Thellufsen, (2021) and Connolly (2015).

B. *The Energy System Analysis*

A reference model of Nigeria's energy system for the year 2017 was created. 2017 was chosen because it is the most recent year with the complete energy data for Nigeria. The inputted data were based on IEA energy balance sheet for Nigeria (IEA, 2019).

The 2030 REMP scenario is in accordance with the Nigeria Renewable Energy Master Plan (ECN, 2005). The Master Plan targets an increase in contribution of renewable energy to electricity generation in Nigeria by 36% in 2030. For other sectors, the reference scenario for the National Energy Master Plan (ECN, 2014) wherein the real GDP grows by a mean of 7% per annum was used to predict energy demand using 2017 as the base year (The National Energy Master Plan used 2009 as the base year). The industry will experience a growth rate of 24.01%, transport 6.46%, household 3.16% and others 6.01%. The electricity supply projection employed in this scenario is also adopted from ECN (2014) (7% growth scenario) and tabulated below.

TABLE I
ELECTRICITY SUPPLY PROJECTION FOR 2030

Fuel Type	Capacity (MW)
Coal	10984
Natural gas	80560
Solar	25917
Hydro	6533
Wind	29
Biomass	54
Nuclear	3500

Source: ECN (2014)

Lastly, the model for the 2050 RE scenario was created. The scenario is aimed at increasing the percentage contribution of renewable energy to electricity supply by > 70%. The energy demand for other sectors was also predicted using the National Energy Master Plan's reference growth scenario. However, the scenario was modified through several steps of iteration to reduce the use of fossil by approximately 30% in the transport sector. This is replaced by the used of biofuel and electric vehicles. The following are the key assumptions made in the design of this scenario:

1. Solar capacity was set at 70 GW, wind 25 GW and hydro 17759.4 MW
2. Natural gas-powered plant capacity for the National Energy Master Plan 7% growth for 2030 was maintained. However, it is assumed there will be construction of new biomass plants and the use of coal is assumed to have phaseout.
3. The transport sector is set to grow according the National Energy Master Plan 7% growth scenario. It is assumed that the number of vehicles per 1000 people will increase from 60 in 2018 (National Bureau of Statistics/ Federal Road Safety Corps, 2018) to 200 in 2050. About 4 million of these vehicles will be electrically powered.
4. 20% of the fuel mix in the transport sector will be biofuel. This is set based on preliminary studies of some literatures (NNPC, 2007; Abila, 2010; Agba, et al., 2010; Ohimain, 2013).

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The electricity demand for 2030 and 2050 was projected based on forecast of population growth (United Nations, Department of Economic and Social Affairs, Population Division, 2017) and power demand estimates in literatures (Olayande & Rogo, 2008; World Bank, 2013; Ezennaya, et al., 2014; GIZ, 2015).

TABLE II
PROJECTED POPULATION AND ELECTRICITY DEMAND FOR NIGERIA

Year	2017	2030	2050
Population (million)*	190.886	264.068	410.638
Electricity demand (TWh)	25.77**	131.50[a]	410.64[a]

*Source: * United Nations, DESA, Population Division (2017)*
*** IEA, 2019*
*[a] Calculations based on * and power demand estimates from literatures*

All the above data considerations were inputted into EnergyPLAN for technical simulation. Østergaard (2009) gives some framework of optimization measures for energy system analyses of renewable energy integration. This study focuses on particularly on electricity generation.

III. RESULTS AND DISCUSSION

A. Reference Model Verification and Validation

A comparison was made between the reference model created in EnergyPLAN, and the actual data of the Nigeria's energy system in 2017 obtained from IEA (2019). This is necessary to ensure that EnergyPLAN can be used to generate accurate simulation result. The validation procedure employed by Ma et al. (2014) and Abdulganiyu (2017) was used in this study. First, the sources of electricity consumed were compared. As shown Table III, it can be observed that there is only a slight difference between the Energy PLAN's simulation result and the actual data from IEA (2019).

TABLE III
COMPARISON OF ELECTRICITY GENERATION BETWEEN EnergyPLAN MODEL AND ACTUAL DATA IN 2017 (TWh)

Production mode	Electricity production (TWh)		Difference	
	Actual 2017	EnergyPLAN 2017	TWh	%
Hydropower	5.52	5.56	-0.04	0.72
Solar PV	0.02	0.02	0.00	0.00
Condensing Power	20.25*	20.19	0.06	0.30
Import/Export	0.00	0.00	0.00	0.00
Total Production	25.79	25.77	0.02	0.08

**Excluding 6.65 TWh which accounts for statistical differences (0.45TWh), energy own use (1.16 TWh) and losses (4.84 TWh)*

Table IV compares total fuel consumption by source obtained from the EnergyPLAN model simulation result and the values in the Nigeria energy balance (IEA, 2019).

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TABLE IV
COMPARISON OF TOTAL FUEL CONSUMPTION IN 2017 AND THE EnergyPLAN

Consumption Mode	Total fuel consumption (TWh)		Differences	
	Actual 2017	EnergyPLAN 2017	TWh	%
Coal	0.34	0.34	0.00	0.00
Oil	219.94	219.96	-0.02	0.01
Natural gas	81.13	85.06	-3.93	4.84
Biofuel/waste	1253.59	1253.57	0.02	0.00
Total fuel consumption	1555.00	1558.93	-3.93	0.25

As can be seen on Table IV, the Energy PLAN data agrees to a large extent with the actual 2017 data. The only observable difference is natural gas consumption which differs by 4.84%. The verification of the reference model developed shows that Energy PLAN can simulate Nigeria's energy system effectively and is therefore, employed to simulate the 2030 and 2050 future scenarios.

B. The 2030 REMP Scenario

This scenario takes into account the Renewable Energy Master Plan targets wherein renewable energy is to account for 36% of the total electricity generation capacity by 2030. The energy demand and supply for the other sectors (industry, transport, household and others) is projected according to the National Energy Master Plan's 7% growth scenario while using 2017 as the base year. The electricity supply is also projected based on the National Energy Master Plan's 7% growth scenario. These data were inputted into EnergyPLAN model, and the results are tabulated below.

TABLE V
FUEL MIX IN THE 2030 REMP SCENARIO

2030 REMP		Total fuel consumption (TWh)	Fuel for power generation (TWh)
Coal		157.21	152.06
Oil		566.31	-
Natural gas		497.65	26.70
Biomass		2639.57	0.47
Renewables	Hydro	24.5	24.5
	Solar	27.4	27.4
	Wind	0.09	0.09
Nuclear		7.26	7.26
Total		3919.99	238.48

From Table V, about 6.59% of the fuel consumption is for power generation. The main driver of growth in this scenario is industry (construction, manufacturing, mining, etc.) with annual growth rate of 24.01%. The transport, household and others (commercial and public services) will be having growth rates of 6.46%, 3.16% and 6.01%, respectively. As can be observed, aside biomass, oil still accounts for the highest share of fuel used in this scenario.

Table VI shows the simulation result for power production. The shift from fossil fuel power plant to renewable energy for electricity generation will result in an increase in the share of renewable energy in electricity production from 20.2% in 2017 (IEA, 2019) to 37.88% in 2030. This is 1.88% more than the Renewable Energy Master Plan target for 2030 (ECN, 2005). In addition, 5.6% of the electricity production will be from nuclear power plant. This is in line with the National Energy Master Plan projection for the year 2030 (ECN, 2014).

TABLE VI
SIMULATION RESULT FOR POWER PRODUCTION 2030 REMP SCENARIO

2030 REMP	Electricity Production (TWh)
Condensing Power Plant	78.55
Nuclear	7.26
Solar	27.40
Hydro	24.50
Wind	0.09
Biomass	0.33
Total	138.13

C. *The 2050 RE Scenario*

This scenario is focused on achieving >70% contribution of renewable energy to power generation and the introduction of electric vehicles and biofuels in the transport sector. The scenario was designed considering the availability of renewable sources in Nigeria (Sambo, 2009), and renewable energy technologies assessment based on several critical sustainability indicators (Evans, et al., 2009). The electricity production was from natural gas power plant, biomass power plant, solar, hydro and wind. Coal-powered plant was assumed to have phaseout due to CO2 content (95 kg/kJ). The simulation result for the power production is shown in Fig. 1. 71.20% of the total electricity production is from renewable energy sources (excluding biomass plants). Fig. 2 shows EnergyPLAN electricity production for a month in 2050.

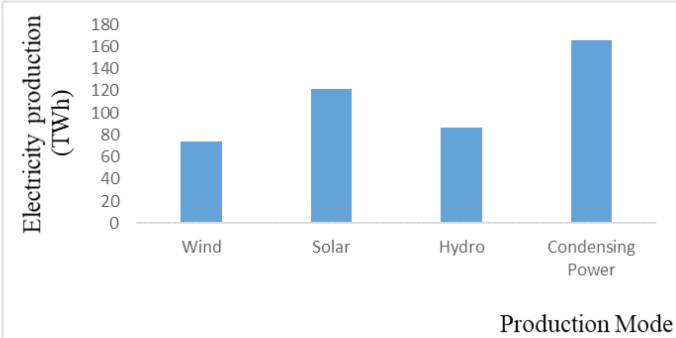

Fig. 1: Simulation result for power production 2050 RE scenario

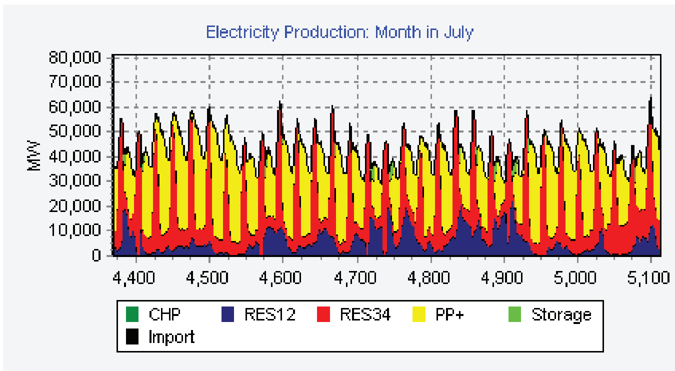

Fig. 2: EnergyPLAN electricity production output in a typical month

RES12–Wind RES34 - Solar PV; PP+- Large hydropower plants + Natural gas plant + biomass plant; Storage–Electricity production from storage and vehicle to grid transportation

In the transport sector, it is assumed there would be four million battery electric vehicles (BEVs) each having 50 KWh rechargeable battery packs, an equivalent of 200 GWh capacity in total. An estimated electricity demand of 24 TWh was set for the BEVs of which 75% would be for dump charge and the remaining 25% would be for smart charge. The maximum share of cars during peak demand was set at 20% and the share of cars that will be grid connected was set at 70%. Table VII shows the fuel consumption in the transport sector for the year 2050.

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TABLE VII
FUEL CONSUMPTION IN THE TRANSPORT SECTOR
2050 RE SCENARIO

2030 REMP	Electricity Production (TWh)
Condensing Power Plant	78.55
Nuclear	7.26
Solar	27.40
Hydro	24.50
Wind	0.09
Biomass	0.33
Total	138.13

It can be observed that fossil fuel still dominates the share of fuel mix used in transport sector in the 2050 RE scenario. This is because vehicles stay on the road for up to 40 years in Nigeria (Maduekwe, et al., 2020) and there is still an increasing market for fossil fuel vehicles, so, therefore, replacing the already existing fossil fuel vehicles would be impractical.

D. Comparison of Electricity Production between the Scenarios

The annual electricity generation in each of the three scenarios is shown in Fig. 3. There is a substantial shift in the generation capacities from fossil fuel power plant-dependent to Renewable energy-dependent. In the 2017 reference scenario, the electricity production from condensing power is 20.19 TWh, 5.56 TWh from hydropower, and 0.02 TWh from solar. Renewable energy account to about 20% of the electricity generation in 2017. In the 2030 REMP scenario, production from condensing power plant is 78.55 TWh, 7.26 TWh from nuclear power plant and 52.32 TWh from renewable energy sources. Renewable energy in this scenario accounts for 37.88% of the total power production. In the 2050 RE scenario, renewable energy share in power generation is increased to 71.20%.

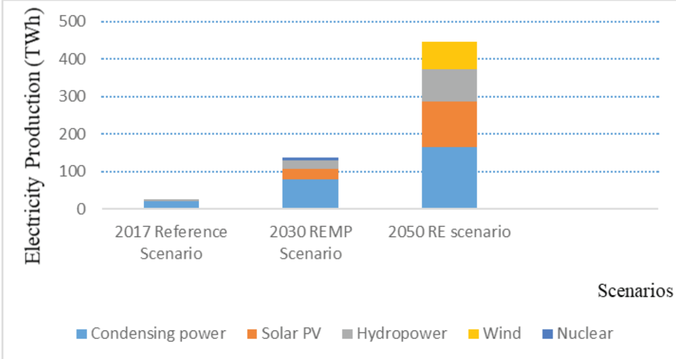

Fig. 3: Electricity generation by source in different scenarios

IV. CONCLUSION

It is evident that Nigeria's energy demand would continue to increase due to the rapid growth in population and the economy. However, the supply which is still dominated by fossil fuel is not sufficient enough to meet such increasing demand. It is pertinent to introduce renewable energy sources which the country has in abundance into the supply mix. In this study, a reference scenario and two energy system scenarios for Nigeria were technically designed and simulated. The 2017 reference scenario was designed to reflect Nigeria's energy supply and consumption in 2017; the 2030 REMP scenario was designed to show a pathway to achieving the Renewable Energy Master Plan target of increasing the supply of renewable electricity by 36% of the total electricity generation by 2030.

The 2050 RE scenario seeks to increase the share of renewable energy by >70% of the total electricity generation; it also introduces the concept of electric vehicles and the use of biofuel in the transport sector. Both the 2030 REMP and the 2050 RE scenarios employed the National Energy Master Plan 7% reference growth scenario for all sectors using 2017 as the base year.

The study shows that with the abundance renewable energy sources in the country, it is possible to develop an energy system whose supply is based on renewable energy. The 2030 REMP shows the shift from fossil fuel power plant to renewable energy for electricity generation will result in an increase in the share of renewable energy in electricity production from 20.2% in 2017 to 37.88% in 2030 while the 2050 RE shows that the share can go up to 71.20% if proper infrastructures and policies are put in place.

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A Case Study of Heat Recovery: A Heat Pump in an Industrial Site

Abaubakry M'BAYE

Energy manager@ GSK, France

mbaye.aboubakry@gmail.com

ABSTRACT

Greenhouse gases cause global warming of the earth. Carbon dioxide is one of those gases. There are different sources of carbon emission such as industrial activities and deforestation. The application of energy efficiency in industrial environment is one lever to reduce carbon emissions. "Waste" heat represents a significant energy saving potential for industrial companies. Thanks to recovery technologies, waste heat resulting from a process that is not used by it can be recovered for other uses within the same plant or outside. In addition to the economic interest, the recovery of fatal heat is very virtuous from an ecological point of view if the recovered energy avoids the consumption of fossil fuel. It thus improves the carbon footprint of an industrial installation. This article is a case study in an industrial pharmaceutical site in France and explains how a heat pump has been implemented. All the steps of the methodology are detailed: deep analysis of waste heat from the site, calculation and measurement of the reuse potential and research of the most suitable technology to carry out this recovery. This study has permits to reduce by 1/3 site's carbon emissions.

Index Terms: *carbon emissions reduction, heat recovery, heat pump.*

I. INTRODUCTION

Fatal heat is the heat "lost" by an industrial process which releases thermal energy. This may be, for example, fumes from combustion, cooling water, vapors, steams, conditioning air, etc.

To recover the fatal heat, heat pump technologies are more and more used which make it possible to recover heat at low temperature and then to reinject it into a fluid at higher temperature [1, 2]. This equipment is complex and consumes electricity, but it nevertheless allows a more efficient heat transfer. They operate using a refrigerant that circulates in a closed loop through an evaporator, compressor, condenser, and expansion valve, and undergoes several changes of state (liquid/gas). This technology has become widespread over the past ten years.

For implementing a waste heat recovery system, the recovered energy must be able to be used, either by saving another primary energy source within the industrial installation, or by being sold nearby, to an industrialist or to an urban heating network. In addition to the purely technical aspects which are complex, it is also necessary to understand the possible intermittences of the recovered energies and the non-simultaneity between the recovered heat and the non-recovered heat.

This case study is about a successful implementation of a heat pump in a pharmaceutical company.

A. Strategy

The philosophy is to consider the energy required by the process and ensure that this energy is delivered in the most efficient way (deliver the maximum savings with minimal capital in the fastest possible timeframe).

For that each cooling/heating system on the site has been considered, first as a discrete system and then as a whole system (there is often the opportunity to combine systems).

It is more precisely a three-phase approach:

1. Before the central plant can be considered (where the large savings are realised), the user loads must be considered. This is the most important stage, and it ensures

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that the process conditions are met in the optimum way.

2. Following this, the distribution system must be analyzed to ensure that the utility is delivered at the correct conditions.
3. Once we have established the correct requirements for the users and distribution system, we can address the generation of the utility and consider energy reduction opportunities at the central plant.

B. *Heat pump introduction*

A heat pump in its simplest form is a refrigeration unit that utilizes the heat normally rejected for heating [3, 4]. The term heat pump is used to cover a variety of applications, including air source or ground source heat pumps, but these reject the cooling either into the air or into the ground and the cooling is wasted. The main purpose of an industrial heat pump is to always use the cooling and the heating to ensure the highest system efficiency.

C. *Refrigerant*

A refrigerant is a fluid that allows the implementation of a refrigeration cycle.

Figure 1 shows a pressure-enthalpy chart for the refrigerant R134a with a standard refrigeration cycle superimposed in red, and a heat pump cycle shown in blue [5].

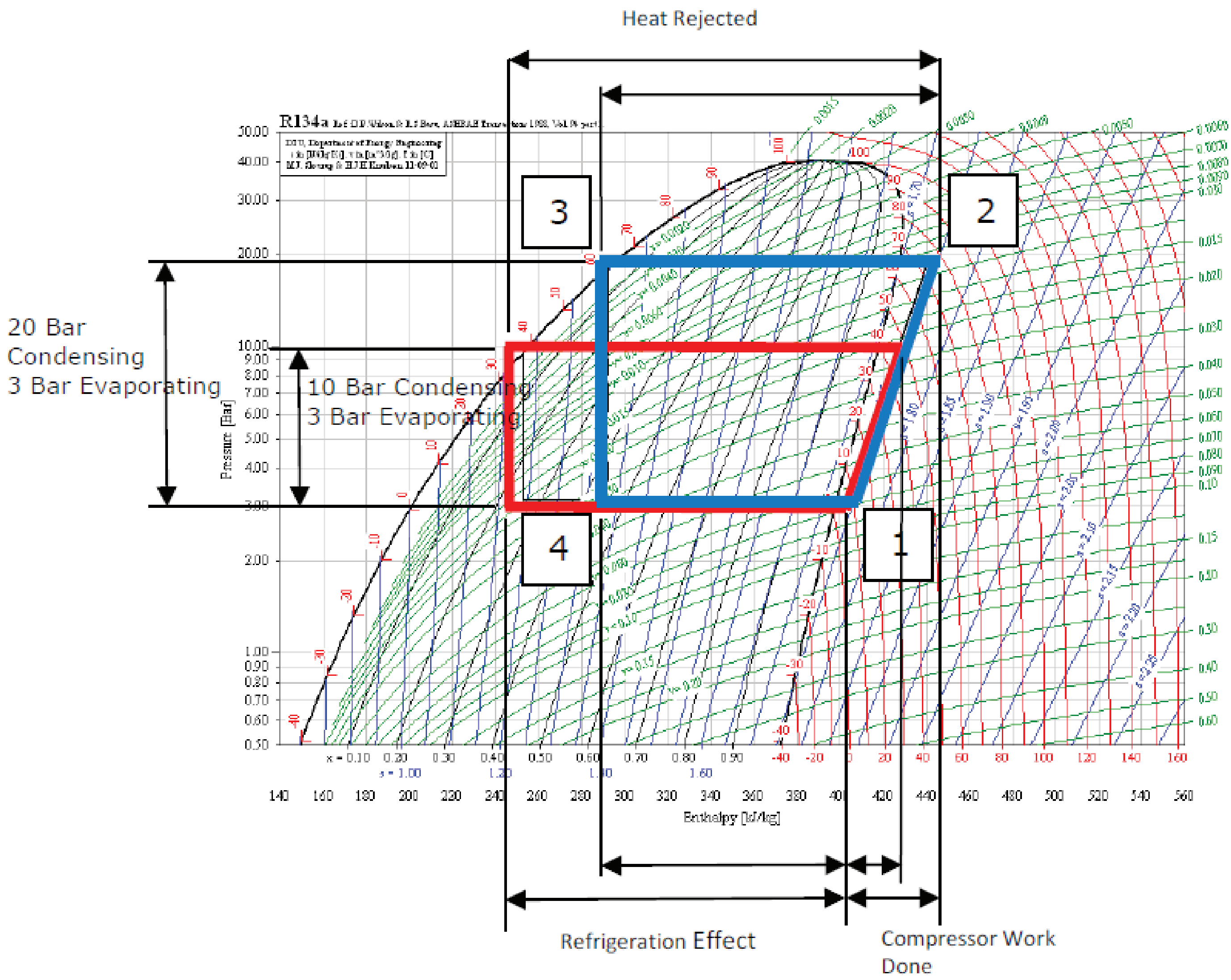

Fig. 1. Pressure-enthalpy chart for refrigerant R134a

As can be seen in figure 1, to create higher grade hot water we need to raise the condensing pressure/temperature, from 10 Bar (45°C) to 20 Bar (65°C). By raising the condensing pressure, this increases the work done of the compressor and the refrigeration duty is reduced. Heat pumps need to be considered as a heating device with cooling as a bonus.

The refrigerant is the working fluid of the system, and refrigerants have different properties that affect their suitability for heat pump applications [6]. To produce hot water at 85°C a condensing temperature of approximately 95°C and 56.6 Bar is necessary.

Research of the most suitable refrigerant for this study:

R404a – This is a common refrigerant, but it is not suitable for high temperature due to a low critical point of 71°C. For any temperature above this point, the refrigerant cannot be condensed and turned into a liquid. Many other refrigerants are of a similar nature.

R134a – This refrigerant has a higher critical point: 101°C at 39.7 Bar. This could be suitable for a heat pump application.

R717- Otherwise known as Ammonia. As soon as we look at high temperature heat pumps, we need to look at industrial refrigeration. The critical point of Ammonia is 132°C at 113 Bar, so we would be working well within the characteristics of the refrigerant. Ammonia has a major inconvenient: it is a health hazard.

R744 – Otherwise known as CO2, this is one of the oldest refrigerants and is currently going through a renaissance. CO2 has many properties that make it attractive for heat pumps, however, to produce hot water in the region of 85°C would require CO2 to work above the critical point of 74 Bar at pressures in the region of 120 Bar range and into the transcritical zone (120 Bar is the maximum pressure of the current compressor technology). Many supermarkets are adopting CO2 technology. However, this technology is still in its infancy, and has not been scaled up for larger industrial duties.

To summarize, whilst there are many refrigerants suitable for heat pumps, R134a is the best choice for this study. Ammonia equipment are also available, but these are bespoke and, whilst they can achieve a higher temperature of hot water, they are more expensive, and ammonia is a health hazard.

II. CASE STUDY DETAILS

A detailed study is launched because it allows the projected solution to be dimensioned, designed, and customized with precision. The first step was to analyze deeply the current chilled water (heat waste emitter) and hot water systems (heat waste receiver).

A. *Chilled Water System*

The chilled water system in the site comprises:

- 1 x 937kWt chiller as represented in figure 2; Manufacturer = Trane; Model = RTHD; Refrigerant= R134a; Manufactured in 2010; Fitted with Variable Speed Drive (VSD)
- 1 x 750kWt chiller; Manufacturer = Trane; Model = RTHC; Refrigerant= R134a; Manufactured in 1996
- 2 x 1005kWt chiller; Manufacturer = Trane; Model = RTHA; Refrigerant= R134a; Manufactured in 1992
- 3 x 15kWe fixed speed primary pumps
- 3 x 15kWe fixed speed condenser water pumps
- 2 x Cooling Towers (2066kWt and 1714kWt); Manufacturer = Evapco; Cooling Towers fitted with 15kWe Variable Speed Drive fan; Manufactured in 2010 and 2015
- A set of secondary pumps (from 1.5kWe to 17.5kWe)

The system is configured as a low loss header/ balance tank system with fixed speed primary pumps and variable speed secondary distribution pumps. There are two balance tanks on the system, one is a smaller balanced tank located in the chiller plant room with three sets of small secondary distribution pumps, the other is a larger balance tank on the second level above the chiller plant room which has five sets of secondary distribution pumps.

The chillers are run with a set point of 5°C. Site has 4 four Trane water cooled screw chillers.

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Fig. 2. 937kWt chiller

The lead chiller (Trane RTHD variable speed screw compressor 937kWt) was installed in 2010. It has a relatively good design efficiency (COP) of 6.56 kWe/kWt when run with 27°C cooling water. The COP of the system improves when run with reduced cooling water temperatures but decreases when run at low part loads. The chiller runs with a chiller set point of 5°C with a refrigerant evaporating temperature of 3.7°C. The chiller is supplied with 23°C cooling water and runs with a refrigerant condensing temperature of 27.5°C.

The 750kWt chiller starts when the demand is high to assist the lead chiller. It is a fixed speed screw compressor chiller that utilizes R134a as a refrigerant. The chiller has the same COP than the biggest chiller. The other chillers also start depending on the demand to assist the two chillers already running (start priority order).
Most of the cooling loads are HVAC providing both room temperature control and dehumidification. There is also a small amount of cooling for the purified water plant, vacuum plant and others process equipment.

B. Hot Water System

The low temperature hot water system in the site comprises:

- 2 x 2500kWt gas fired hot water boilers: Manufacturer = Guillot
- 3 x 3kWe fixed speed primary pumps (duty/standby/spare)
- 2 x 15kWe VSD speed secondary distribution pumps (duty/standby) supplying hot water to process equipment
- 2 x 15kWe VSD speed secondary distribution pumps (duty/standby) supplying hot water to HVAC
- 2 x 3kWe VSD secondary distribution pumps (duty/standby) supplying hot water to the washer
- 2 x 1kWe VSD speed secondary distribution pumps (duty/standby) supplying hot water for domestic water system
- 2 x 0.75kWe VSD secondary distribution pumps (duty/standby) supplying hot water to Administrative Offices heating

Site has a central boiler control system which automatically stops and starts the boilers and primary pumps. This system also opens and closes the actuated hot water isolation valves on the boiler. The system is configured as a low loss balance/header system with fixed speed primary pumps and fixed speed secondary distribution pumps. Typically, one boiler primary pump is run per boiler.

The boilers such as the one represented in figure 3 are conventional water storage boilers with a large volume of hot water stored within the boiler. Such boilers have a typical efficiency of approximately 80%. When running at low boiler loads (i.e., less than 40%) the efficiency of the boiler will reduce slightly down to approximately 75% as the storage losses increase. The boilers control themselves to maintain the required hot water temperatures in the hot water system.

Fig. 3. Hot water boiler

The hot water system is run at different temperatures depending on the day of the week and the season. During the week the hot water system is run at 84°C, this is increased to 90°C in the middle of winter to enable the washer to maintain the required water temperatures when the inlet water temperature is low. Out of production hours, i.e., over the weekend the systems water temperature is reduced to 70°C as production plant is not in use.

The hot water user loads can be split into the following groups:

- **Washer water heater:** The washer heater is a heavy-duty heat exchanger which utilizes hot water to heat domestic water or purified water for use in the washer up to a minimum temperature of 55°C.

- **Washer drying air battery:** There is a drying process at the end of washing process which utilizes hot dry air generated by the washer drying battery. The washer drying battery is a relatively small heating battery that heats 100% fresh air up from ambient temperatures to 70°C.

- **Air Pre-treatment for Coating equipment:** Site has 4 coater units which require a supply of hot dry air. This hot dry air is generated using a combination of desiccant dryers and air heating batteries. Hot water is used to preheat the regeneration air on the desiccant dryers. The typical air temperatures achieved using the regeneration air preheaters is 60°C. The desiccant driers also have electric heating elements which are used to heat the regeneration air up to the required regeneration temperature of 120°C. When running, both the hot water heating and electric heating elements are run at 100% to maintain the required air regeneration temperature. If the temperature of the hot water is decreased below 80°C, the performance of the coating equipment is adversely affected. The coating machines also have a hot water heating coil which is used to heat the dried process air leaving the desiccant dryer. The temperature of the process air leaving the desiccant dryer is typically 30-40°C and needs to be heated to 60 to 65°C.

- **Heating batteries for desiccant dryers of heating ventilation and air conditioning (HVAC) systems:** Site has 20 desiccant dryer dehumidification units which are used to control the humidity levels in the rooms. The humidity set points in the rooms vary from 20 to 50% Relative Humidity (RH). Most of the desiccant dryers (17 of the 20 unit) utilize hot water to pre6 heat the regeneration air with electrical heating elements integral to the units being used to further heat the air up to the required desiccant regeneration temperatures. This regeneration temperature varies depending on the amount of dehumidification that needs to be achieved. The temperature of the air leaving the hot water air preheating batteries is at approximately 60°C. Site has a HVAC turndown procedure for weekend operation, where some HVAC units are turned off and other units have their temperature control and humidity control dead band limits extended.

- **Heating Batteries for HVAC room temperature control:** Some of the HVAC units also have small frost coils installed on the fresh air supply which is used to prevent the HVAC coils from freezing when outside ambient air temperatures are low (less than 0°C). They are relatively small heaters and are supplied from the same hot water pumps as the HVAC heating batteries. As these batteries are only heating air to 5-10°C there should be no issues with running these units with water down to 60°C if required.

- **Frost coils for HVAC equipment:** Some of the HVAC units also have small frost coils installed on the fresh air supply which is used to prevent the HVAC coils from freezing when outside ambient air temperatures are low (less than 0°C). They are relatively small heaters and are supplied from the same hot water pumps as the HVAC Heating Batteries. As these batteries are only heating air to 5-10°C there should be no issues with running these units with water down to 60°C if required.

- **Offices heating batteries:** There is a separate set of hot water secondary distribution pumps used for heating the offices for comfort control. Such as for the HVAC heating batteries, it is expected that these units will operate running with 60°C hot water as air off temperature of 18-22°C are required. The system is also very small with the secondary distribution pumps only being 0.75kWe.

- **Sanitary Water for Domestic Use: There is a separate sanitary** hot water circuit which circulates around the site for supplying 50°C water for hand washers, etc. This system is heated using hot water from the main hot water system via a heat exchanger in the plant room. There is a dedicated 1kWe pump set which is used to supply hot water to the heat exchanger. The pump is configured as an attemperation loop

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and controlled to maintain the 50°C sanitary hot water temperature in the system. The sanitary hot water system would be able to maintain the required temperature if the temperature of the main hot water system was reduced to 60°C.

III. HEAT LOST AND HEAT NEED

A. *Heat Lost Capacity*

To determine the heat lost capacity, all the data have been gathered and analyzed with the help of a software dedicated to chiller system. After calculation, the heat lost capacity of chilled water system is 15.8 GWh GCV/year (GCV = Gross Calorific Value) as shown in TABLE I.

TABLE I. HEAT LOST ESTIMATION BY CALCULATION

Heat Lost	Fluid	Flow (m^3/hour)	Temperatures Entry (°C)	Exit (°C)	Power (kW)	Duration (hour/year)	Energy (MWh GCV/year
Cooling Towers	Water	200	25	23	418	8 751	4 957
Chillers	Water	297	7	4	986	8 751	10 833

Then, the calculations have been verified through measurement, thanks to instrument and software. Figure 4 represents flow, entry and exit temperatures.

Below is the correspondence of the curves in figure 4:

- Green curve = Flow; Average = 263 m3/h
- Red curve = Entry temperature; Average = 6.7°C
- Blue curve = Exit temperature; Average = 4.3°C

We can observe that calculation and measurement results are close (also the measuring accuracy of the devices is to be considered).

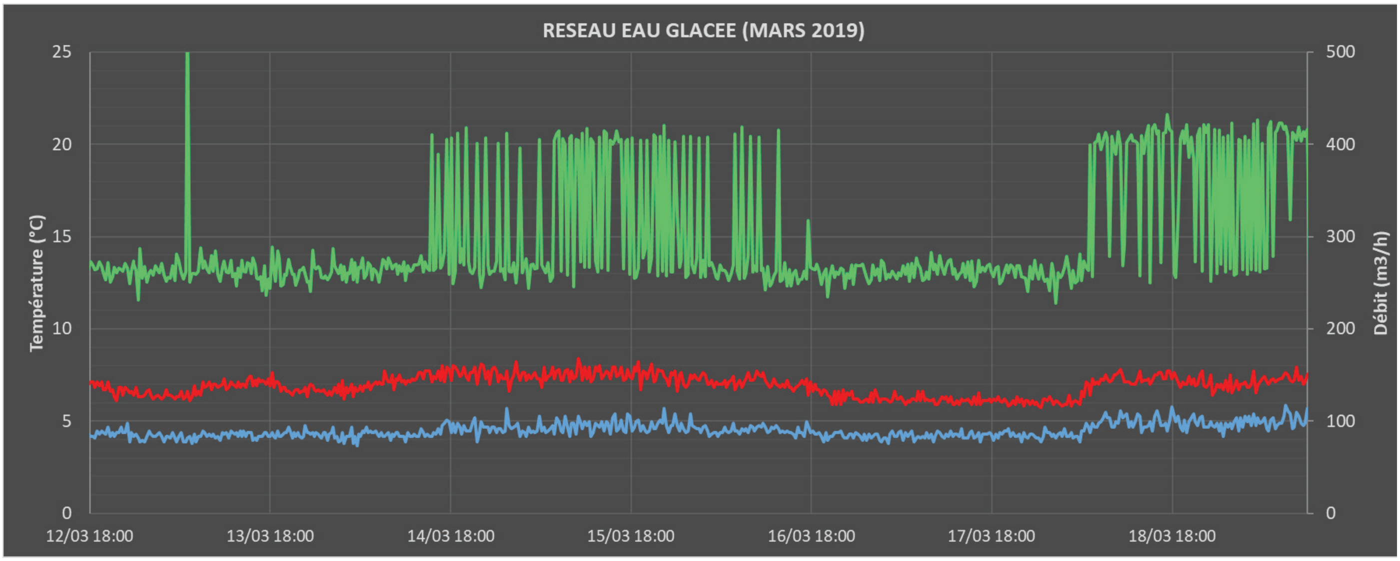

Fig. 4. Heat lost estimation by measurement

B. Heat Need

To determine the heat need, all the data have been gathered and analyzed with the help of a software dedicated to hot water system. After calculation, the site heat need is 4.9 GWh GCV/year as shown in TABLE II.

TABLE II. HEAT NEED ESTIMATION BY CALCULATION

Heat Need	Fluid	Flow (m^3/hour)	Temperatures Entry (°C)	Exit (°C)	Power (kW)	Duration (hour/year)	Energy (MWh HHV/year)
Hot Water (boilers)	Water	107	77	80	453	8712	4951

Then, as for heat lost, the calculations have been verified through measurement, thanks to instrument and software. Figure 5 represents flow, entry and exit temperatures.

Below is the correspondence of the curves in figure 5:

- Purple Curve = Flow; Average = 105 m3/h
- Green curve = Start Temperature; Average = 81.0°C
- Orange curve = Return Temperature; Average = 75.7°C

The heat lost can satisfy the site need on hot water. Nevertheless, there is a seasonality effect to take into consideration.

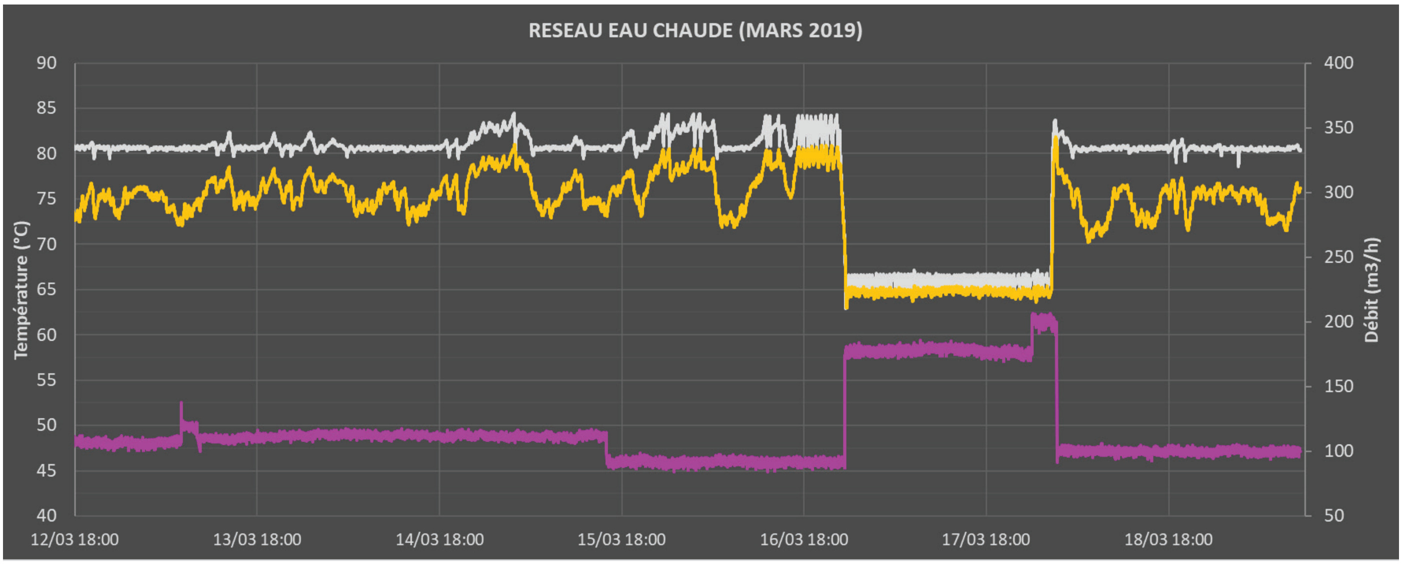

Fig. 5. Heat need estimation by measurement

C. Heat Pump Selected

The manufacturer of the heat pump is Ochsner (Austrian company). As seen in figures 6 and 7, it is an equipment with large dimensions.

Below are the main characteristics of the heat pump:

- Type of refrigerant and quantity: R134a/130 kg
- Heat pump weight: 4400 kg
- Range regulation: 50% to 100%
- Display touch screen
- Modbus communication
- System state: temperatures, pressures, time running operation, percentage load, electrical consumption, default fault, etc.
- Settings: art walk / stop via Modbus or contact, selecting set point, etc.

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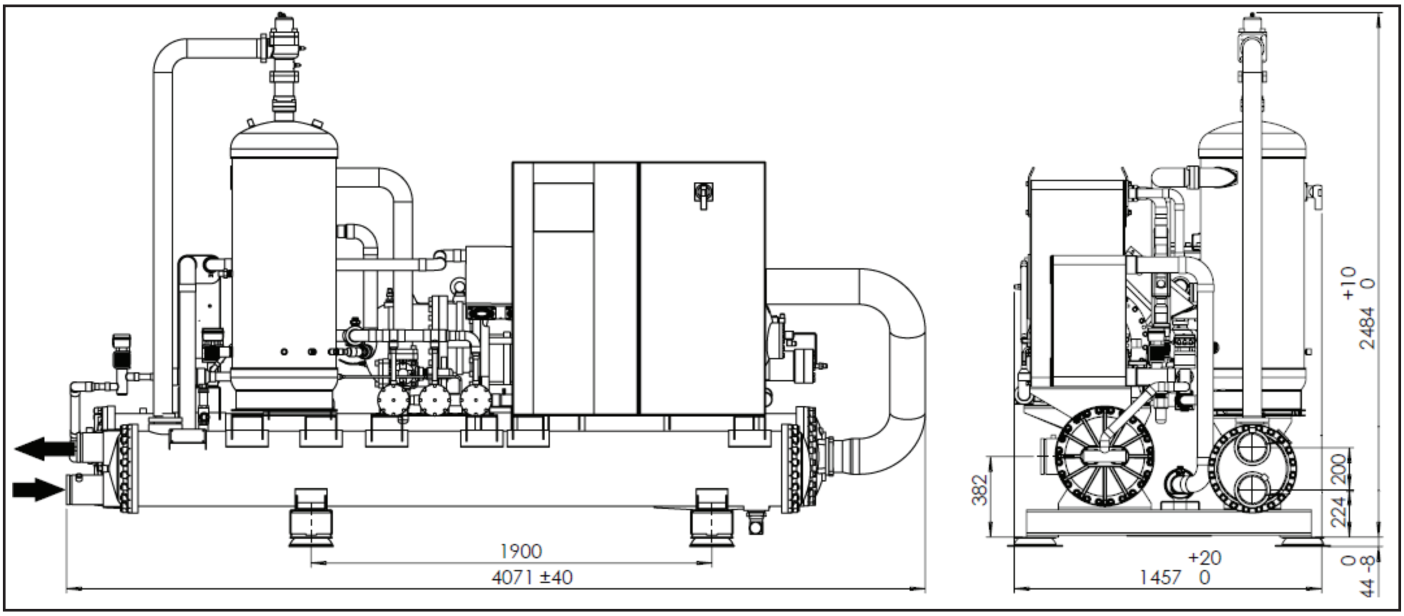

Fig. 6. Front and side drawings of the heat pump

Fig. 7. Rear view picture of the heat pump

D. Design of the Whole Heat Pump Installation

As shown in figure 8, the heat in the water entering in the cooling towers and the heat in the water entering the chillers are taken and reinjected in the hot water installation [7].

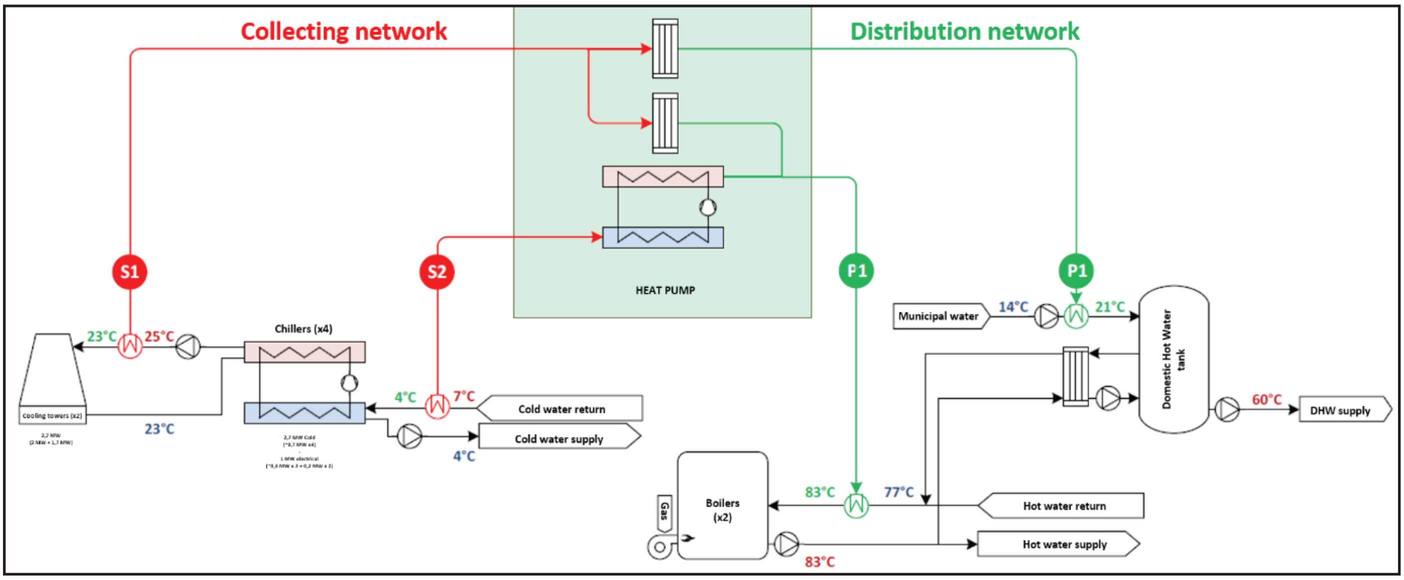

Fig. 8. Heat pump P&ID

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Below are some key data:

- Combustion efficiency = 93%
- Distribution efficiency = 95%
- Distribution efficiency of the recovery network = 98%
- GCV (Gross Calorific Value) / NCV (Net Calorific Value) = 1.11
- Heat pump power = 680 kWt
- Installation COP = 2.8
- Temperature regime: 90/85 °C

Several equipment/elements are in place in addition to the heat pump itself:

- Production Skid
- A new electrical supply cabinet
- An insulated water tank (7 m3)
- Pipes network and insulation
- Heat-exchanger
- Instrumentation (temperature and pressure sensors...)
- Program logic controller (PLC)
- Variable speed drive pumps

E. Heat Pump Future Performance

The energy produced by the heat pump reduces by nearly 70% the energy (gas) used for the hot water loop as seen in figure 9.

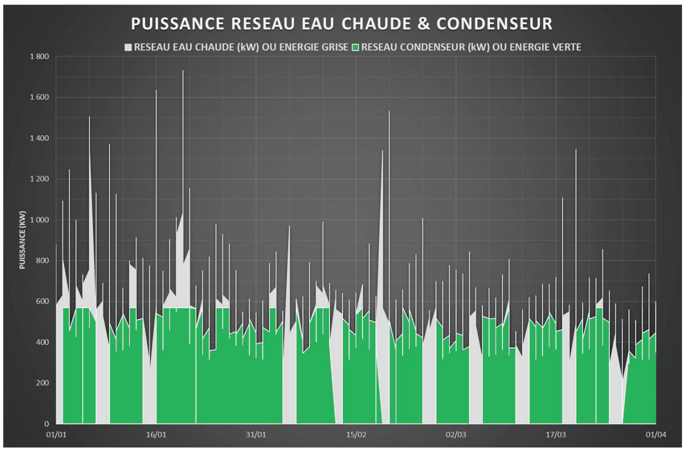

Fig. 9. Hot water system power (in gray) versus heat pump power (in green)

Figure 10 illustrates the savings on carbon emissions, water consumptions, and costs. Site's carbon footprint is reduced by 1/3, thanks to this major project.

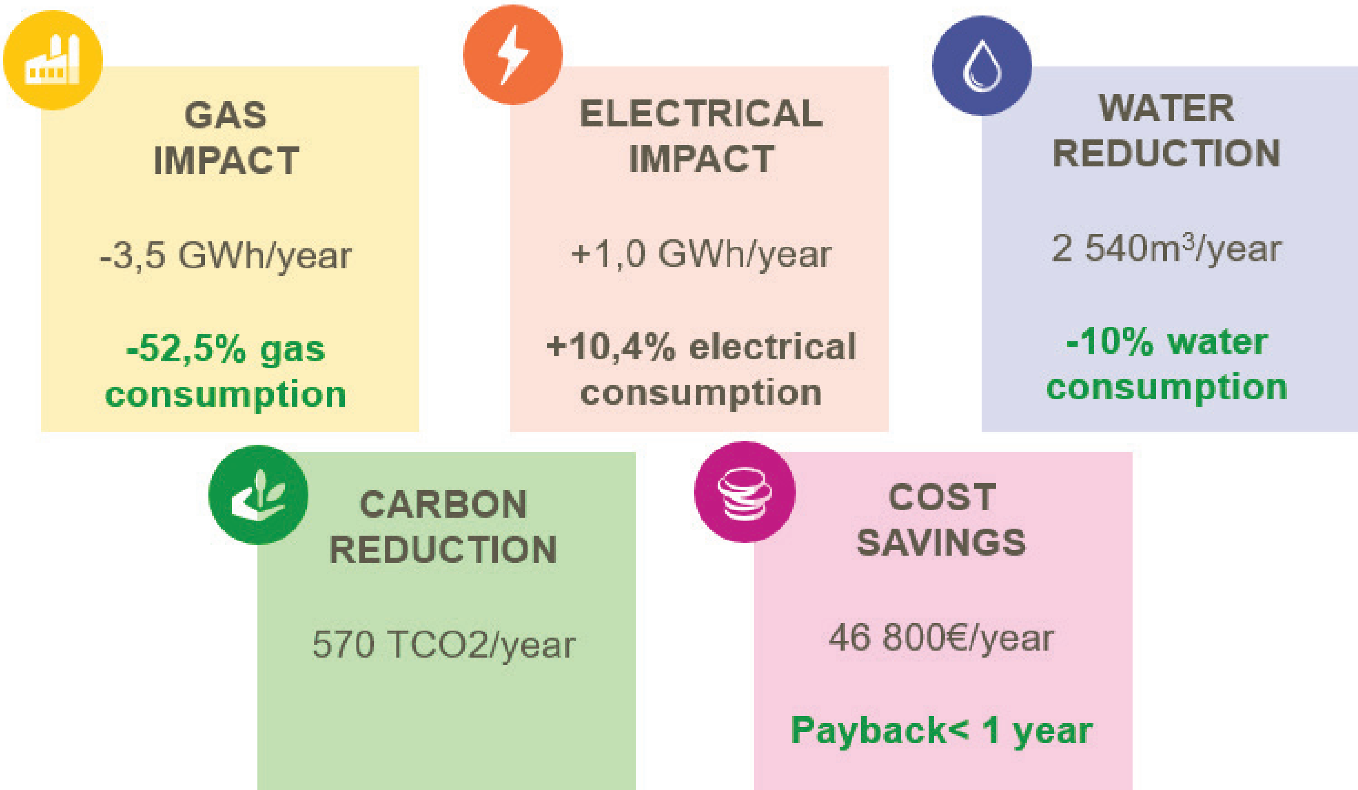

Fig. 10. Heat pump savings

Installation status and performances are monitored through a dedicated supervision.

F. Actual Performance of the Heat Pump

Date (month-day)	Site's actual gas comsumption (kWh)	
	Year 2021	Year 2020
September 15	2300	14030
September 16	3565	13915
September 17	2760	15065
September 18	0	13915
September 19	6325	7935
September 20	6325	6670
September 21	2300	14605
September 22	5405	16445
September 23	3105	16100
September 24	4600	17250
September 25	0	16330
September 26	0	8510
September 27	1725	7475
September 28	7130	15180
September 29	3565	17250
September 30	8050	16445
October 1	7590	16905
October 2	4830	18055
October 3	7590	9890
October 4	9660	9200
October 5	5175	17710
October 6	7015	17710
October 7	10235	18860
October 8	4025	16560
October 9	805	15985
October 10	7245	9200
October 11	9085	8740
October 12	7245	20010
October 13	5635	19320
October 14	6785	21620
October 15	6095	21735
Daily average gas consumption (kWh)	5038	14794
Period's gas consumption (kWh)	156170	458620

Fig. 11. Actual site's gas consumption from mid-September to mid-October 2021 versus 2020

Figure 11 shows that site's gas consumption has been reduced by 66%, mainly thanks to the heat pump. Other factor can impact site's gas consumption such as production and external temperature (10% in this period). Gas consumption reduction is aligned with estimation (remind = 52.5%).

IV. CONCLUSION

This paper adds to the literature on heat recovery (with a heat pump) a new case study. Where a chilled water system exists, the opportunity to install a water source heat pump for reducing consumption and therefore carbon emissions should be studied.
For a successful implementation of a water source heat pump the system emitting the heat lost and the system receiving this heat lost have been deeply analyzed. Estimations have been made through calculation and measurement. The heat pump has been dimensioned and selected based on those last elements and on technical research on refrigerant.

Then, the estimated savings (reduction of carbon emissions by 1/3) have been confirmed after the implementation and commissioning of the heat pump.

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RESILINK: Increasing Resilience of Smallholders with Multi-Platforms Linking Localized Resource Sharing

Congduc Pham

UPPA, STEE, LIUPPA laboratory, Avenue de l'Université
64000 PAU CEDEX, FRANCE

Congduc.Pham@univ-pau.fr

Dr Congduc Pham is a Professor of Computer Science at the University of Pau (France). He obtained his Ph.D in Computer Science in 1997 at the LIP6 Laboratory (University Paris 6, Pierre and Marie Curie). His current research interests include wireless sensor networking, Internet of Thing, congestion control/resource allocation and QoS for cloud computing infrastructures. He has published more than 140 papers in international conferences and journals, and gave more than 80 tutorials/keynotes and scientific presentations.

In H2020 WAZIUP and H2020 WAZIHUB, he is the scientific expert on Internet-of-Thing and LoRa technology and developed the LoRa IoT generic framework used in these projects. He also produced numerous tutorials and IoT kits to be used in hackathons and training sessions.

In H2020 HUBIQUITOUS he is leading the deployment of SolutionLab for providing access to IoT and AI disruptive technologies in Digital Innovation Hubs in Africa. He is also coordinating the PRIMA Intel-IrriS project on smart irrigation for smallholders, where IoT and AI technologies will be deployed for smallholders to facilitate their access to smart-agriculture.

I. INTRODUCTION

Agriculture is an important sector for income generation, employment and food security in the whole African continent. Increasing the resilience of smallholders to face unexpected crises such as COVID-19 is an increasing concern with recent numerous publications on this subject [1, 2, 3, 4]. The main difficulty resides in the fact that it is a multidimensional challenge that requires a multifaceted policy [5, 6, 7].

However, common to most crisis situations, the restrictions on movements have many impacts on the availability of distant resources such as agricultural supplies, equipment, services, labours and access to markets to name a few.

RESILINK is a Research & Innovation Action (RIA) project funded by the PRIMA organization in the context of the 2021 Section 2 call on Increasing the resilience of small-scale farms to global challenges and COVID-like crisis by using adapted technologies, smart agri-food supply chain and crisis management tools. RESILINK increases smallholder's resilience by providing continuity of access to both resources and markets in crisis situations. It empowers the local agri-food value chain model by optimizing usage of local resources, promoting and generalizing local resource sharing approach and facilitating territorial markets. This local agri-food value chain model will also be integrated with the local e-commerce, supply and distribution channels.

The concept of localized and short agri-food value chain will also impact the agro ecological system by minimizing food losses and contributing to climate and environment changes with shorter food supply chains and logistics. As a result, new and local innovative services can be identified and created, enhancing further the smallholders' agri-food chain.

To implement the generalizing local resource sharing approach, RESILINK develops a distributed digital resource management platform for real-time exchange of information on territorial resources, supplies and demands; connecting smallholders to new supply, sharing opportunities and distribution channels.

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While the ideas of connecting smallholders to market and sharing resources are not new [8, 9, 10, 11], the approach taken by RESILINK is to provide a unique platform-of-platforms capable of integrating existing or future platforms into comprehensive dashboards/portfolios. To achieve its objectives, RESILINK:

- develops a resilient RESILINK network ensuring high availability of services;
- implements the platform-of-platforms approach for large-scale adoption and sustainability;
- uses cutting-edge modern Artificial Intelligence to efficiently discover resources;
- seamlessly integrates Internet-of-Things (IoT) technologies to automatize a number of information exchanges; and runs an extensive piloting and evaluation program with smallholders;

An important contribution of RESILINK is to run an incremental piloting and evaluation program to maximize smallholders' acceptability, large-scale adoption and a sustainable usage of RESILINK's platform even in non-crisis situations. Finally, RESILINK addresses local innovation capacity and facilitates technology appropriation by developing the digital intelligent resource management platform in open-source with an extensive public API to maximize re-utilization and facilitate the integration of new platforms.

The rest of the article is organized as follows: Section Two presents an overview of the RESILINK digital platform, its main components and how seamless integration of IoT and Artificial Intelligence (AI) technologies improve resource discovering and sharing. Section Three then elaborates on the challenging research issues behind the implementation and the deployment of the RESILINK digital platform. Conclusions are presented in Section Four.

II. THE RESILINK DISTRIBUTED DIGITAL RESOURCE MANAGEMENT PLATFORM

RESILINK platform uses advanced digital technologies and state-of-the-art architectures and protocols for flexible and real-time information exchanges targeting sharing and discovery of local resources. It deploys a resilient network ensuring high availability of services where a number of light-weight platforms can be installed on local servers hosted at regional or city-level or even at the community level by socio-economic organizations such as Chambers of Commerce, cooperatives, government agencies, start-ups/SMEs, etc. The platform can also be installed in a distributed way so that several platforms can operate simultaneously to manage resources according to geographical areas. Each of the distributed platforms can share the information on territorial resources.

Figure 1 sketches the overall proposed framework with following RESILINK components: the digital resource management platform, the mobile application, the Edge-IoT components and the API and software API connectors/wrappers to link with other third-party digital platforms.

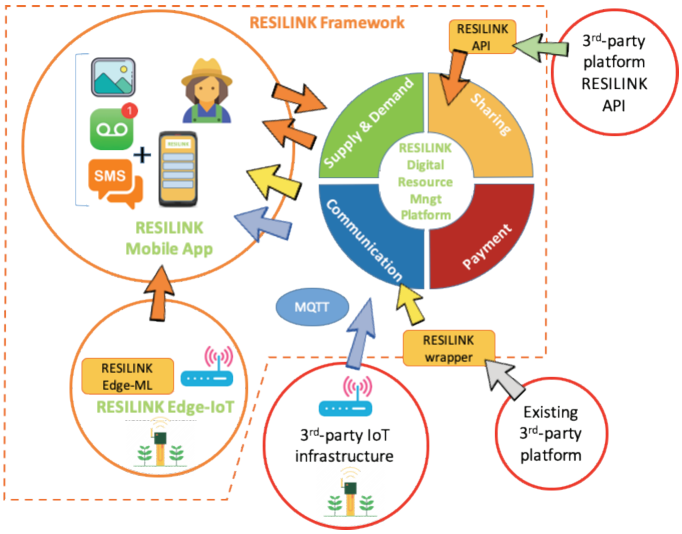

Fig. 1 – Overview of the RESILINK framework

A. Platform-of-platforms Design Approach

In order to promote the generalized resource sharing approach and to maximize long-term adoption, RESILINK also implements a platform-of-platforms design approach to propose a much wider and appealing ecosystem: (a) RESILINK wrapper components enable resources from existing digital platforms to be discovered and integrated and, (b) RESILINK's open API allows development of new digital sharing platforms that can fully inter-operate with the RESILINK digital resource management platform to benefit from the RESILINK community. The lightweight, highly scalable and standardized MQTT protocol [12] is used as the foundation for the open API to provide the full set of functionalities. A limited set of functionalities can be provided with the more traditional REST API.

B. Integrating IoT and AI Technologies

Smallholders will interact only in a very simple manner with the digital resource management platform, indicating available resources and offered resources. Based on previous experience gained from more than six years of international collaborations with smallholders in both North and Sub-Saharan African countries, the authors know that acceptability and usage can be low if the proposed interface is too complex.

In RESILINK, while inputs from end-users are kept simple, cutting-edge digital technologies in IoT, Linked Data, Decision Support System (DSS) and AI are designed to provide advanced features to efficiently connect smallholders to resources, matching demands to offers in an intelligent manner. For instance, IoT devices (such as push buttons, tags readers, environmental sensors and field sensors) deployed for specific tasks can automatize a number of simple processes. Then, Linked Data and DSS are integrated into low-cost and compact IoT edge gateways can process multiple knowledge streams to efficiently notify smallholders (alarm, SMS,...) on relevant events such as discovery of resources, availability of resources, request for resources, localization of resources, etc.

In Figure 1, the RESILINK Edge-IoT component takes care of IoT and AI features and is deployed in a fully edge approach by embedding them into the IoT gateway itself, meaning that the RESILINK digital platform is also distributed in a number of edge components that run on IoT gateways.

III. RESEARCH and DEVELOPMENT CHALLENGES

A. A Lightweight Edge-enabled Platform

The whole RESILINK framework providing resilience to smallholders should itself be resilient to crisis situations. In RESILINK, the digital resource management platform is the central component connecting smallholders to territorial resources and the normal operation mode is to deploy the digital resource management platform on local servers at regional or city level or community level. Therefore, there is a challenging research issue on building such a distributed and resilient network of lightweight digital platforms while preserving consistency and synchronization between the Edge-IoT component of the RESILINK digital platforms running on Edge-IoT gateways.

B. Increased Robustness with Blockchain-based Transactions

As the core of RESILINK digital platform is to handle a large number of transactions for sharing agri-food chain resources, it is quite natural to adopt a Blockchain approach [13, 14] to ensure robustness of the decentralized transaction system. Blockchain technologies have been investigated in a large variety of applications [15] and RESILINK, with its private and decentralized architecture particularly investigates how private/permissioned, peer-to-peer and hybrid Blockchain frameworks provide a possible solution to problems with a single point of failure and bottleneck.

C. Data Privacy and Traceability

While transactions and related databases operations can be made more robust with Blockchain, more complex data management features are highly desirable when dealing with smallholders' data on resource demands and sharing offers, including for instance those from automatized collected IoT data [16]. Such concerns on data management are becoming more and more critical especially as an increasing number of countries are adopting regulations similar to the EU General Data Protection Regulation (GDPR) [17]. By proposing and implementing efficient data management methods, RESILINK would increase the level of trust with smallholder users, therefore maximizing large-scale adoption of the technology. Data privacy, data provenance, data traceability as well as innovative digital identity approaches are the challenging research issues that will be conducted by RESILINK.

D. Investigating innovative AI approaches

While the integration of AI technologies may seem nowadays easier with the increased maturity of the research domain, the traditional data models in AI usually assume a simple data exchange model. In these traditional models, one entity would build and transfer sets of data to another entity which is in charge of cleaning and fusing the data. The AI data processing chain could include additional entities, each providing at its level its own AI approach to build new models for other users. When implemented on top of a highly-distributed architecture, with the constraint on secured data management, this traditional way of running AI has to face data fragmentation and data isolation issues. Recently, decentralized AI approaches have been proposed to tackle these issues and RESILINK will investigate federation-based AI [18, 19] or gossip-based AI approaches [20].

IV. CONCLUSIONS

This article presented a general overview of the PRIMA RESILINK project to increase smallholder's resilience by providing continuity of access to both resources and markets in crisis situations. It proposes a generalized local resource sharing approach for the smallholder's agro-food chain and has the clear ambition to make digital smart technologies attractive and accessible to smallholders.

There are several expected impacts. First, the authors expect RESILINK to have an important impact on sustainability and competitiveness by promoting digital smart technologies to improve efficiency and by creating new business opportunities towards the smallholder communities. Second, RESILINK can also directly improve efficiency of small-scale farming system as generalized usage of local resources can reduce both delays and cost of access to resources. Finally, while RESILINK focuses on a generalized resource sharing platform for smallholders, the technology building blocks developed by RESILINK can easily be adapted to a larger variety of application domains. The large networks of actors built during the project will create synergies, increasing the likelihood of innovative third-party applications by local entrepreneurs for instance.

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