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Analyzing the Impact of Theft and Vandalism in Relation to the Sustainability of Renewable Energy Development Projects in Sub-Saharan Africa

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Abstract: Theft and vandalism impede the sustainability of renewable energy (RE) development projects in Sub-Saharan Africa. Therefore, it is essential to explore where these crimes originate from, how they propagate and how they can be counteracted. In our study, we analyze the impact of these disturbances on implemented projects. We utilize a consumer clinic approach to generate data that represents the situation. We define our instigators practically (Government Inequality, Crime to Survive, Sabotage) and demarcate the actions of the offenders into 4 types: (1) vandalization of small RE projects (SPv); (2) theft of RE infrastructures from small RE projects (SPt); (3) vandalization of large RE projects (LPv); and (4) theft of RE infrastructures from large RE projects (LPt). To counteract these actions we define three types of security interference: human, societal and technical. We model the career of an RE criminal as a multi-stage Markov model. In every stage the offender can commit any of the offences SPv, SPt, LPv, LPt, or go to rest. Transition probabilities are our means to reflect offender maturity. Crucial to our model is that they are affected by the level of interference installed at the project site. Calibrated on a dialogue with 144 respondents, our Markov model directs us to adequate interferences per project. Specifically, for large projects technical and human security are the most effective, whereas, for small projects we recommend societal security. The paper introduces a mathematical model of the career of a RE-offender including the influence of security interference and calibrates the parameters through an ethnographic approach.

Keywords: renewable energy; sustainability; theft and vandalism; Sub-Saharan Africa; crime perception; project failure

1. Introduction

Across Sub-Saharan Africa (SSA), the dissemination of renewable energy technologies (RETs) is currently soaring. The sustainability of the publicly implemented projects is being questioned as vast numbers of these projects are deserted after their commissioning [1]. Factors that affect the sustainability of these projects range from the utilization of inexperienced personnel during and after the implementation, the unsustainable management of the project after implementation, inappropriate location selection, absence of protection of the infrastructure from theft and vandalism, unsuitable technological utilization etc. However, in this study, our focus is on the protection of RE infrastructure and the impact of theft and vandalism on the sustainability of the implemented projects. Our research is focused on developing a model based on stochasticity to model the offenders' career path and to identify beneficial levels of interference measures based on the type of projects. In this study, the level of interference is described as the level and type of security an offender may encounter based on project type and location when attempting to vandalize or purloin RE related infrastructures. The level of interference is expected to deter offenders, increase difficulty and prolong the time spent on

attempting to vandalize or loot RE related infrastructures. It is paramount to ascertain the instigators that lead to the theft and vandalism of these projects and incorporate those into the model. In this way interferences can be designed to effectively counter the operations of the offenders considering the project type and locations. Furthermore, there exist recent technological solutions that may be considered in the implementation of RE projects that include sensors, short messaging services (SMS) etc. [2] to thwart the potential of theft and vandalism.

This study aims to analyze the impact of theft and vandalism in relation to the sustainability of renewable energy development projects in Sub-Saharan Africa. In addition, we attempt to further determine the actions and interferences that could hinder the sustainability of these projects being thrown into disarray, whilst considering the principal instigators, project types and already existing levels of interference. Given that no data exists in line with our study, we utilize a crime perception approach combined with the scenario approach [3] in generating the data required to validate our model. A Markov theory approach is utilized which contains (i) three different instigators (government inequality, crime to survive and sabotage), (ii) five different states (theft of RE infrastructures from small projects, vandalism of small projects, theft of RE infrastructures from large projects, vandalism of large projects, and a rest state), and (iii) K stages (i.e., the progressive career of the offender[s]). This research determines adequate interferences that should be utilized per project type and location and in turn further prolongs the lifeline of the projects thus attaining their sustainability statute. This study is further motivated by the state of the current energy infrastructure that has also been marred by ill-management, theft and vandalism. Since the aspect of sustainable development is an important characteristic of RE development projects, our aim is to analyze the impact that disturbance could have on these projects when not considered prior to implementation.

The planning and implementation of theft and vandalism prevention techniques to RE development projects in Sub-Saharan is a topic that has been circumvented. Nonetheless, it is an important characteristic that must be considered for these projects to be sustainable. To the best of our knowledge, there currently exists no literature that focuses on the aspects of disturbances such as theft and vandalism to RE development projects in SSA. However, numerous papers and mathematical models have been published with respect to disturbances such as theft and vandalism in general. In addition, there are multiple reports [4] on the protection of RE projects from theft and vandalism as the issue plagues not just the developing countries in SSA but is also felt in the developed countries [5]. The issue of theft and vandalism has also resulted in the slow phasing out of PV projects in some countries in Southern Africa [6].

One important method as discussed by Stander et al. [7], is the utilization of Markov theory in discrete-time to analyze the specialization of offenders. Markov theory has long been utilized to model and predict criminal behavior, whereby it also elucidates the occurrences of events through time [8]. Modeling the criminal career and characteristics of an offender has always been a major challenge for criminologists [9]. Bartolucci, Pennoni & Francis [10] utilized a multivariate latent Markov model to analyze the drawback associated with ascertaining behavioral patterns of offenders from historically available data, whilst focusing on the categorization and classification of crimes committed by offenders.

Most criminal studies are based on the availability of historical data. However, since the availability of data in our study is infeasible we chose for the generation of our own data via the implementation of a survey. This is crucial in our study as it also presents the basis for the development of the transition probabilities. In doing so, we adapted the classical approach by Hauser et al. [11] that uses a consumer clinic to obtain data to calibrate the sales trajectory of a new car. Where these authors use advertising to increase sales, we use interference to reduce offences.

The approach applied by our research has overtime been substantiated by crime scientists and criminologists in measuring crime seriousness perceptions [12–14] *"Crime perception is a complex phenomenon including much more than judged seriousness. Crime stereotypes are shown to be coherently organized around a few basic perceptions such as level of violence, amount of property harm, etc. While the*

data affirms that there is agreement about judged seriousness, it suggests significant disagreement regarding crime stereotypes. Different people adopt different crime stereotypes. These differences are related to social variables. The most important theoretical conclusion is that agreement about any single crime perception, including seriousness, does not imply agreement about other features" [15]. Several studies have been successful in utilizing the approach of respondents' self-reported intention to offend (scenario method), compared to the traditional reports of actual behavior, this approach has been presented by Nagin and Paternoster [3] as described—"*Data are assembled using a survey that presents respondents with a scenario describing in detail the conditions under which a crime is committed. Selected scenario conditions are experimentally varied across persons. Respondents are asked to estimate the probability that they would commit the act specified in the designed scenario, the chance that their commission of the offence would result in arrest and in exposure without arrest, and questions designed to measure their perceptions of the costs and benefits of committing the offence described in the scenario. More so, the scenario method differs from conventional data collection approaches in perceptual deterrence research in only one important respect. Instead of using self-reports of one's own criminal involvement or alternatively self-reports of future criminal intentions as the response variable, the scenario method uses offending scenarios to elicit the response variable.*"

Employing the approaches presented above, the interest of this paper is to analyze the level of impact that theft and vandalism could potentially possess on the sustainability of renewable energy development projects in Sub-Saharan Africa (SSA) and more importantly to provide solutions and recommendations to be utilized by government bodies and organizations towards future attacks (vandalism and theft) on publicly and or privately funded renewable energy (RE) projects in Sub-Saharan Africa. Given the history in most SSA countries with respect to the inequitable distribution of wealth, these circumstances have more often than not led to the vandalism of public infrastructures [16] and in some cases theft, which is a product of rioting and protest against the ruling government. In South Africa for example, over 380 million Rands (approx. 24 million Euros) is spent per year on security guards to curtail the issue of theft and vandalism [17]. However, the problem of theft and vandalism still persists. In Nigeria where oil is the main source of revenue, the vandalization of pipelines and theft of crude oil costs the country billions in revenue per year and in turn drastically affects the generation of electricity [18–20]

Contributions of this study are the following:

- A mathematical model of the career of any offender ruining the sustainability of renewable energy development projects.
- An analysis of the impact of theft and vandalism to RE development projects taking into account realistically defined instigators.
- A measurement approach to calibrate the career model of an offender(s), despite the absence of pre-existing data, via a crime perception data generation technique.
- The provision of interference levels based on project type and location to prolong the sustainability of the project.
- The introduction of the concept of attraction in order to determine the effectiveness of a specific level of interference.

The remainder of the paper is structured as follows. In Section 2 we present our materials and methods. In Section 3 we describe our experiments, results and further present an in-depth analysis and discussions on the results. Finally, Section 4 presents our conclusions and recommendations for the future.

2. Materials and Methods

2.1. Model Formulation

The model formulation presented in this research amalgamates multiple quintessential factors. Government inequality (GI), crime to survive (SU) and sabotage (SA) are the most influential instigators

that lead to the vandalism and theft of renewable energy related infrastructures. These instigators have been carefully selected as they are representative of reality to the situation of theft and vandalism of public infrastructures in Sub-Saharan Africa. The basis of this selection has been on interviews with project developers, financers and project beneficiaries as also described in Ikejemba et al. [1]. In our model, we further demarcate the aspect of theft and vandalism to both small and large implemented RE development projects. We briefly explain each of the three instigators considered in this study below and further explain in the section of our generic model conception about the delineation of our model.

Government Inequality: With the unfair distribution of national wealth and resources happening often in SSA, this usually leads to unrest around most nations. As such, people tend to express their frustration by vandalizing infrastructures and engaging in illicit activities that could provide them with the resources to survive on a day to day basis. In this scenario, we refer to the theft and reselling of solar panels and other RE related infrastructures. However, this is not to say that government inequality totally stimulates the vandalism and/or theft of public infrastructures, or in this case renewable energy development projects. Nonetheless, the ineffectiveness and failures of the government to effectively create jobs, social security and other basic necessities arouses the anger within the people and as such leads to the vandalization of implemented public projects of which RE development projects are not spared.

Crime to Survive or Survival: The issue of committing a crime to survive has always been debated in several African countries, most notably, South Africa [21]. Several cases have been reported about the theft and vandalism of RE related infrastructures in countries like Nigeria, Kenya, Ghana, South Africa and Gabon [22–24], where solar panels have been taken off project sites. One very surprising incident was reported in Botswana where a telecommunication corporation utilizes RE to provide access to telecommunication networks for people in rural areas. Nevertheless, for every three panels implemented or replaced two of the panels were reportedly stolen [25]. This unfortunately leaves most of the villages without access to telecommunication network and more importantly diminishes their belief in RE. Nevertheless it is believed that these circumstances are a product of government inequality.

Sabotage: Ikejemba et al. [1] indicated that the failure of RE projects is caused by various issues. One of them is sabotage, where projects that are locally implemented cannot withstand the rigors of in-fighting amongst locals. In this instance, RE projects implemented in a specific community are attacked by individuals from a neighboring community out of "jealousy". The result of sabotaging these RE projects is the larceny of the related infrastructure implemented in a specific community. Just as with respect to crime to survive, sabotage is not necessarily influenced by government inequality. However, the likelihood of projects being sabotaged cannot be ruled out to being influenced by government inequality. This theory is based on the assumption that if every community possesses the basic energy needs that should be provided by the ruling government, the need for sabotaging implemented projects in other communities would reduce or cease to exist.

Government inequality, sabotage and the committing of crime to survive with respect to both public and private RE development projects are not necessarily the only instigators that exist but are predominantly the main causes of theft and vandalism. Another contributing factor to the problem is the aspect of non-inclusion, which is the situation whereby RE projects are implemented without the involvement of the local communities. One of the consequences of non-inclusion as described by Ikejemba et al. [1] is the unsustainable management of the projects which also in turn could lead to desertion and ultimately, theft of the RE related infrastructures. The instigators presented above are the predominant instigators that lead to the vandalism and theft of RE related infrastructures in SSA. However, it is important to note that vandalism is usually considered the secondary option to theft or a crime of resentment. The factors presented above were considered so as to be able to model the nature of the situation in SSA. In the next section we present our generic model conception and provide further analysis on the vandalism and theft of RE related infrastructure in SSA.

2.2. Generic Model Conception

Several studies have been carried out using Markov theory to analyze criminal offences and prevention. However, none of the studies have been published in the aspect of modeling the impact of offenders in SSA that vandalize and purloin RE related infrastructures thereby negatively influencing the sustainability of these development projects. In a study by Stander et al. [7], it is indicated that the probability of offenders switching from one crime to another being constant over time is questionable: the past does influence the future, thereby violating one of the supposition of a Markov theory. In addition, little to no study takes into account the aspect of interferences in transiting from a prior stage to another.

In this study, we intend to model the career of an RE criminal. We employ Markov theory, but we add memory to it in the following way. We mimic the career of a criminal by introducing the concept of stages. These are natural steps in the criminal career. Instead of using only states like 'an offender vandalizes an RE project' we add maturity to it by discriminating between stages. So our state definition may e.g., be 'an offender vandalizes a RE project in the third stage of his career'. Transition probabilities will be reflecting criminal maturity.

We distinguish five basic types of offence:

- SP_v—(shorthand (i = 1)) (attempt to) vandalize a small RE project.
- SP_t—(shorthand (i = 2)) (attempt to) steal from a small RE project
- LP_v—(shorthand (i = 3)) (attempt to) vandalize a large RE project.
- LP_t—(shorthand (i = 4)) (attempt to) steal from a large RE project.
- Rest—(shorthand (i = 5)) no attempt to vandalize or steal from any RE project.

With small projects we denote projects that directly impact at most 100 individuals. For example, a modest number of photovoltaic cells, solar cookers, etc. Large projects—impacting more than 100 people—are often prestigious projects, such as solar street lightning of an entire city.

The *level of interference* is the level and type of security an offender may encounter when attempting to vandalize or purloin RE related infrastructures. It is important to note that the probability of impeding theft and vandalism to a specific project is influenced by the level of interference encountered at the specific project. In this study we consider three types of interferences:

- Human Security—refers to the usage and application of individuals or groups (human beings) to protect against theft and vandalism of RE development projects. Familiar situations include the outsourcing to security organizations.
- Societal Security—refers to the utilization of the local communities as interference towards protecting against the theft and vandalization of RE development projects implemented towards the development of the corresponding communities.
- Technical Security—refers to the application of technological infrastructures such as, cameras, sensors, GPS trackers etc. to protect locations of implemented RE development projects from being breach and the related infrastructures from theft and vandalism.

The way an offender reacts to a specific interference is depending on the stage of his career. A first offender may be expected to react stronger, than a recidivist. Below it is shown how we model the influence of interference in the transition probabilities associated with the various stages.

2.3. Model Development

In this section we present our Markov model including the assumptions utilized in the development of the model.

Model Assumptions

- Between offences committed from the third attempt on (in stage 3, k = 3) up until the final stage (k = K), very little substantial difference exists. (i.e., we assume that an offender isn't likely to change his decision over that period of time).
- Majority of offenders are likely to become offenders instigated by the inequality of the government via failure to create jobs and provide basic necessities to survive. Nonetheless, we present this as a hypothesis of which we test in the data generation Section 3.

Further assumptions utilized in the model & data generation are presented in Section 3.

Introductory Remarks and Notation

Throughout, we use the following notation:

Indices
i,j: (type of) offence (i,j = 1,2, . . . ,5), defined above
k: stage of criminal career (k = 1,2, . . . ,K)

States
(i, k): with i type of offence and k stage of criminal career

Parameters
$\boldsymbol{\Delta_i}$: level of interference performed for type of offence i = 1, 2, . . . , 4
$\boldsymbol{q_{(i,k)(j,k+1)}}$: offence transition probabilities with no interference
$\boldsymbol{p_{(i,k)(j,k+1)}}$: offence transition probabilities in case of interference

The corresponding transition matrices are denoted by $\boldsymbol{Q^k}$ and $\boldsymbol{P^k}$, respectively.
We write

$$\boldsymbol{p_{(i,k)(j,k+1)}} = \boldsymbol{q_{(i,k)(j,k+1)}} \boldsymbol{A_{ij}^k}(\boldsymbol{\Delta_i}) \text{ for } i,j = 1,2,\ldots,4,\ k = 1,2,\ldots,(K-1)$$

where, $\boldsymbol{A_{ij}^k}(\boldsymbol{\Delta_i})$ denotes the attraction of committing offence j in stage $k+1$ after committing offence i in stage k given that offence i has a level of interference $\boldsymbol{\Delta_i}$.

All parameters are non-negative.

It seems plausible to expect that the attraction $\boldsymbol{A_{ij}^k}(\boldsymbol{\Delta_i})$ is non-increasing with increasing level of interference $\boldsymbol{\Delta_i}$. In Section 3.1.1 we test this hypothesis.

As shown in Figure 1, the initialization stage consists of the initial rest [I] with specific probabilities transitioning to any of the three instigators (Government Inequality [GI], Crime to Survive[SU], Sabotage[SA]). Given that the weighted impact of government inequality on the issues of vandalism and public disturbance is the highest of all instigators, we expect that the transition probability $\boldsymbol{p_{I\_GI}}$ from initial rest (I) to government inequality (GI) will be greater than the transition probability $\boldsymbol{p_{I\_SU}}$ from initial rest (I) to crime to survive (SU) and also greater than the transition probability $\boldsymbol{p_{I\_SA}}$ from initial rest (I) to sabotage (SA). Summarizing: $\boldsymbol{p_{I\_GI}} > \boldsymbol{p_{I\_SU}}; \boldsymbol{p_{I\_GI}} > \boldsymbol{p_{I\_SA}}$.

In the first stage, we distinguish four states, i = 1, 2, 3, 4. State 5 is excluded, since our aim is to model the career of a criminal which is not supposed to start off as a rest state. In the other stages, as shown in Figure 1, the rest state is present. Note that as of state 1 all transitions are between states in subsequent stages.

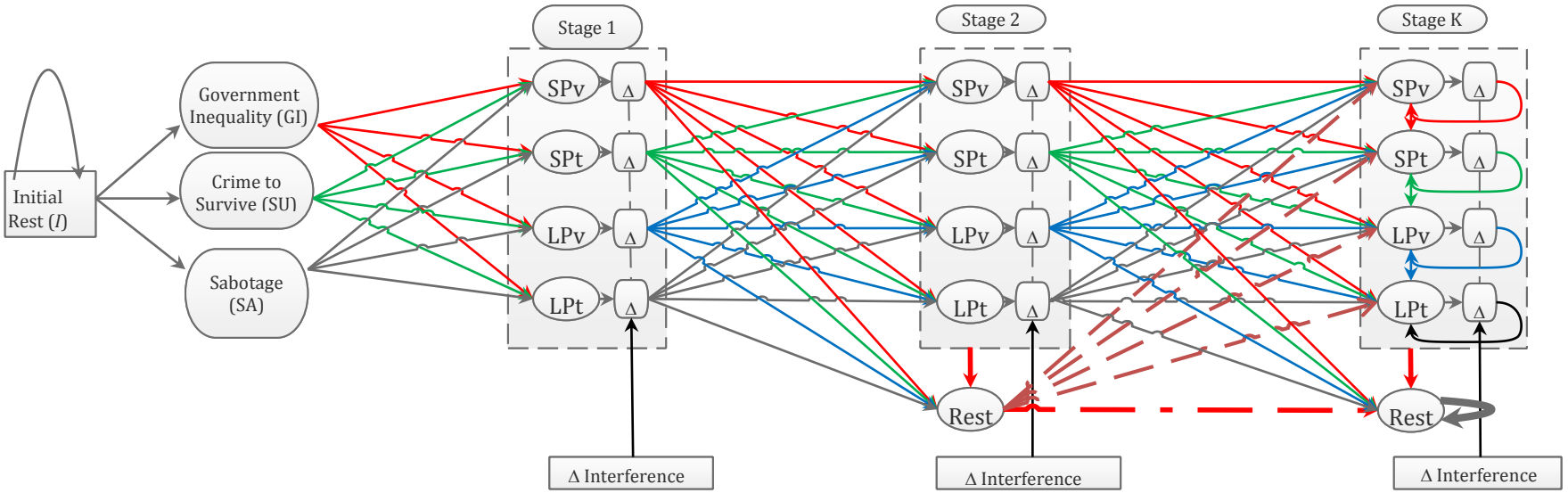

Figure 1. The Complete K-Stage Model.

3. Results and Discussions

As previously indicated the introduction, the approach of crime perception is an important fragment of the study of social life. The methods or process in which individuals perceive crime is an intermediate aspect of normative culture in general and formal social control [12]. Sellin and Wolfgang [26] contend that to judge the earnestness of crime as a societal quandary, the prevalence of criminal behavior should not be the only criteria to consider, but also the nature of which the acts have been committed. The authors further suggest that the rate of crime being utilized should be amalgamated with measures of the seriousness of offence. Giving that the seriousness of committed offences are usually judged by legal experts and law enforcement, the researchers utilized an alternative measure of perceived seriousness, one that mirrors public opinion. This measure is the perceived seriousness of crime, one that is acquired by the empirical measurement of perceptions [12]. Theoretically, measuring popular perceptions requires the utilization of probabilities from the general population and in our case, the intricate phenomenon of crime perception in Sub Saharan Africa centers around theft and violence. Motivated by the above, our aim is to explore the feelings towards crime perception of the average citizen. This approach provides data that pragmatically represents the situation in Sub-Saharan Africa and is thus expected to provide solutions in the same regards. Furthermore, it is used to calibrate our model to analyze the impact of disturbance such as theft and vandalism to renewable energy development projects within the region. Our survey involved the questioning of individuals across SSA. This was executed individually with each participant in an uncontrolled environment to avoid the contamination of our data generation. To make sure that our data is representative, we selected 144 respondents randomly. The participants were paid €40 for their participation. The dialogue was implemented in two phases. In the first phase we questioned the individuals in a structured manner without the implementation of interference. In phase 2 we introduced the aspect of interference.

Commencing phase 1, the participants are asked, from three different selections of instigators (Government Inequality (GI), Crime to Survive (SU) and Sabotage (SA)), which is most likely to instigate them into committing an offence of either vandalizing or purloining an RE infrastructure from a project location. Based on the response provided, subsequent questions are asked on what sort of offence they are likely to commit based on four given choices: (1) vandalization of small RE projects (SPv), (2) theft of RE infrastructures from small RE projects (SPt), (3) vandalization of large RE projects (LPv) and (4) theft of RE infrastructures from large RE projects (LPt). An illustration of the process can be seen in Figure 1. Subsequently, they are asked what offence they are likely to commit next, provided that the opportunity presented itself again, although in this scenario a rest (R) choice is added to the previously outlined four choices. This is repeated for a third and fourth scenario. The participants are subjectively allowed to switch between offences whilst moving from one stage to another. However, in the fourth scenario, also known as the stage K scenario, they are informed that in this scenario the offence committed is indicated as a continuum. The illustration can be seen in Figure 1.

In phase 2 of the dialogue, although like the first phase, we introduce the aspect of interference. The commencement of the dialogue is similar to that of the first phase with the selection of an instigator. Without specifying any interference, we ask the participants which of the four offences they would choose as their first offence if they would suspect some kind of interference. Thereafter, the three types of interference are introduced to the participants. To recall, as indicated in Section 2.2, the interference types are Human Security (HS), Societal Security (SS) and Technical Security (TS). The participants subjectively rank these interferences on scale of least to maximum difficulty. These rankings allow us to clearly estimate the difficulty of each of the interferences. Based on the ranking of the interferences, the individuals are asked to select their next potential offence. However, in this case they choose from the options SPv, SPt, LPv, LPt or R (Rest). This selection procedure is repeated over the rest of the stages and as earlier stated, the last stage is presented as a stage of continuum.

Utilizing the data we generated in the above way, we are able to successfully extract the transition probabilities required to extensively carry out the analysis. Throughout the survey, we aim to generate data that is as pragmatic and representative as possible. Several comments were made by participants about the choices they made, such as why they were made and how the chosen offences could be different in certain scenarios connected to the original instigator.

Our approach for data generation stems from the fact that no data concerning the study focus was available in any of the countries across Sub-Saharan Africa. Nonetheless, during the dialogue session with participants, approximately 21% indicated that they have previously engaged in the act of either theft or vandalism to RE development projects. From these 21%, 53% were instigated by the choice of survival (i.e., theft and resell of RE infrastructure). Some of the participants told us about the profitability of such activities. In their experience, currently, only very few individuals have any idea of the advantages of such projects. As long as the locals are not involved as stakeholders in the projects, it is an easier avenue for them to purloin RE infrastructure, as several of the participants indicated.

In Section 3.1.1 we show that 56% of the participants were instigated by inequality from the government, whilst 36% and 8% were instigated by the will to survive and by sabotage, respectively. Generally, most of the participants instigated by government inequality and survival indicated that their first choice of action would be to engage in theft rather than vandalize a project since most projects around the region are small scale projects. However, most also indicated that vandalism would be a secondary option if theft isn't possible. Most of the participants instigated by GI stipulated that they were tired of the current economic and political situation, stating that if jobs were present their participation in theft or vandalism of RE projects would be minimal. Furthermore, the fact that in most projects implemented around the region, the locals aren't even considered as stakeholders makes these projects easy targets. Although few participants selected sabotage as an instigator, almost all were focused on the vandalization of either small or large projects. Some indicated that they were worn out from the fact that some of the politicians implement these projects in their own districts while proxy communities are left without options and as such the act of jealousy prevails and leads to the vandalization of projects. Ikejemba et al. [1] also discuss the aspect of jealousy and sabotage in their study on the failures of RE development projects in SSA, which is a reflection of the reality portrayed by the participants in this study. Participants of the survival instigator were clear on the fact that their aim is to purloin RE related infrastructure for the purpose of reselling. Some indicated that they were willing to quit committing the offence if the socio-economic situation around the regions changes positively.

In the second phase of perception data generation, we asked the participants to rank the security interferences from least to maximum in terms of difficulty. Based on aggregation the societal security (SS) was ranked as the most difficult security with human security (HS) coming in next and then technical security (TS). However, this is based on aggregation—as most individuals are most scared of societal security—and also dependent on the kind of projects. Nevertheless, the aspect of "jungle justice" is the reason most of the participants indicated societal security as the most daunting. *Jungle justice is the concept and act of disregarding the rule of law and taking matters into one's hands; more clearly put, it is the act of handing suspected criminals over to the hands and mercy of an angry mob*. In cases where we questioned the participants about their choice of action without indicating the type of security present, most were likely to select the same as when interference doesn't exist. However, on indicating that societal security was the implemented interference in terms of protecting the project, 100% of the participants indicated that they would either go to rest and visit other project locations or just exit the system totally. In comparison to other sort of interferences, some indicated to go to rest and return whilst others indicated they would change their action from theft to vandalism and from small to large projects as the case may be. Participants instigated by survival indicated that although societal security is more often the hardest to bypass, technical security is the most important because vandalization of the infrastructures isn't profitable to them. Nonetheless, the aspect of societal security

is only possible if the local communities are involved as stakeholders and presented with an incentive on the basis of the projects.

3.1. Calibration of Markov Model

In this section we use the data generated to calibrate our model. Section 3.1.1 gives transition and state probabilities under no to min interference. Next, we discuss in Section 3.1.2 how a mild form of interference influences the behavior of an offender. Finally, we focus on Medium and Max Interference in Section 3.1.3. We derive the associated probabilities and discuss their properties.

3.1.1. Transition and State Probabilities for No to Min Interference

Based on the data analyzed and compiled, we extract in this section the transition probabilities for all relevant stages for the following two cases: (i) no interference and (ii) min interference, i.e., with the least security interference (see Tables 1 and 2).

Table 1. Transition Probabilities without Interference.

Q^{Init}	*SPv*	*SPt*	*LPv*	*LPt*
GI	0.23	0.35	0.13	0.3
SU	0	0.85	0	0.15
SA	0.83	0.17	0	0

Q^{1}	*SPv*	*SPt*	*LPv*	*LPt*	*R*
SPv	0.57	0.29	0	0	0.14
SPt	0.08	0.53	0.05	0.09	0.24
LPv	0	0	0.5	0.4	0.1
LPt	0.13	0.09	0.22	0.44	0.13

Q^{2}	*SPv*	*SPt*	*LPv*	*LPt*	*R*
SPv	0.3	0.22	0.15	0.28	0.06
SPt	0.26	0.19	0.08	0.39	0.08
LPv	0	0.13	0.27	0.53	0.07
LPt	0.02	0.08	0.33	0.5	0.08
R	0.2	0.21	0.09	0.32	0.18

Q^{3}	*SPv*	*SPt*	*LPv*	*LPt*	*R*
SPv	0.07	0.01	0.13	0.04	0.75
SPt	0.07	0.04	0.09	0.04	0.76
LPv	0.04	0.02	0.18	0.14	0.62
LPt	0.03	0.02	0.13	0.1	0.72
R	0.07	0.07	0	0.07	0.79

Table 2. Transition Probabilities with Least Security Interference.

P^{Init}	*SPv*	*SPt*	*LPv*	*LPt*
GI	0.18	0.45	0.08	0.3
SU	0.12	0.73	0.04	0.12
SA	0.67	0.17	0.17	0

P^{1}	*SPv*	*SPt*	*LPv*	*LPt*	*R*
SPv	0.39	0.36	0.07	0.11	0.07
SPt	0.24	0.41	0.04	0.14	0.17
LPv	0.2	0.1	0.2	0.4	0.1
LPt	0.03	0.17	0.2	0.43	0.17

P^{2}	*SPv*	*SPt*	*LPv*	*LPt*	*R*
SPv	0.20	0.13	0.17	0.38	0.14
SPt	0.27	0.18	0.1	0.33	0.13
LPv	0.04	0.07	0.36	0.32	0.21
LPt	0.03	0.07	0.37	0.38	0.15
R	0.26	0.21	0.12	0.31	0.1

P^{3}	*SPv*	*SPt*	*LPv*	*LPt*	*R*
SPv	0.02	0	0.04	0.06	0.88
SPt	0.02	0	0.07	0	0.9
LPv	0	0.02	0.07	0.02	0.9
LPt	0.01	0	0.06	0.03	0.9
R	0.03	0.03	0.03	0.03	0.9

For the initialization stage—depicted in Figure 1—we find from our data analysis the following values for the probabilities transitioning from initial rest [*I*] to any of the three instigators (Government Inequality [GI], Crime to Survive[SU], Sabotage[SA]):

$$\boldsymbol{p}^{Init} = (p_{I\_GI},\ p_{I\_SU},\ p_{I\_SA}) = \left\{ \begin{array}{ccc} 0.5556 & 0.3611 & 0.0833 \end{array} \right\}$$

Note that $p_{I\_GI} > p_{I\_SU}$ and $p_{I\_GI} > p_{I\_SA}$. Hence our expectation from Section 2.3 comes true. A vast majority of the offenders is driven by government inequality.

Let the state probabilities in stage k be given by the row vector $\boldsymbol{q_k}$ in case of no interference and by $\boldsymbol{p_k}$ in case of least security interference. From the above we find the state probabilities for the first four stages (see Table 3).

Table 3. State Probabilities for No Interference and for Least Security Interference.

No Interference						Least Security Interference					
	SPv	*SPt*	*LPv*	*LPt*	*R*		*SPv*	*SPt*	*LPv*	*LPt*	*R*
$q_1 = p^{Init}\ Q^{Init} =$	0.1944	0.5138	0.0694	0.2223		$p_1 = p^{Init}\ P^{Init} =$	0.1945	0.5278	0.0695	0.2083	
$q_2 = q_1\ Q^1 =$	0.1804	0.3473	0.1111	0.1736	0.1874	$p_2 = p_1\ P^1 =$	0.2222	0.3264	0.0903	0.2153	0.1459
$q_3 = q_2\ Q^2 =$	0.1840	0.1735	0.1588	0.3903	0.0932	$p_3 = p_2\ P^2 =$	0.1806	0.1389	0.1945	0.3477	0.1385
$q_4 = q_3\ Q^3 =$	0.0484	0.0279	0.1172	0.0825	0.7236	$p_4 = p_3\ P^3 =$	0.0139	0.0069	0.0554	0.0282	0.8958

3.1.2. The Influence of Min Interference on the State Probabilities

Comparing no interference to min interference, several differences and similarities may be observed. We start on an aggregate level by examining the state probabilities from Table 3.

We find the following:

Firstly, although the matrices Q^{Init} and P^{Init} differ somewhat, the first stage state probability vectors q_1 and p_1 are nearly identical. In both cases the majority of offenders (around 52%) opt for stealing from a small RE project as their first offence. Secondly, we observe that for the next two stages the state probability vectors q_k and p_k display the same pattern:

- In both cases, the popularity of stealing from a small RE project decreases monotonically as stages go on.
- On the other hand, in the third stage, stealing from a large RE project is preferred by 39% and 35%, respectively. In the first stage, this was only 22% and 21%.
- Vandalizing small RE projects is stable over the stages and attracts roughly 20% in both cases.
- Vandalizing large RE projects increases in popularity over the stages from 7% in stage 1 to 16% and 20%, respectively, in stage 3.

Thirdly, the fourth stage state probability vectors q_4 and p_4 differ significantly in the percentage of offenders at rest, 72% versus 90%. This suggests that, in the long run, security interference, even in a weak form, may be effective.

Next, let us examine the influence of min interference on a more detailed level by scrutinizing the transition probabilities displayed in Tables 1 and 2.

3.1.3. The Influence of Min Interference on the Transition Probabilities

The matrices Q^{Init} and P^{Init} show that offenders instigated by government inequality (GI) are not that outspoken in the choice of their first offence. On the other hand, in both cases, first offenders committing Crime to Survive (SU) are focusing on stealing from small RE projects (for 85% to 73%, respectively). Obviously, the instigator Sabotage (SA) leads the first offender to a preference for vandalizing (primarily for small projects, namely 83% and 67%, respectively).

For the transition between stages we are interested in the behavior of $A^k_{ij}(\Delta_i)$, the attraction of committing offence j in stage $k+1$ after committing offence i in stage k given that offence i has a *min* level of interference Δ_i. Purpose of any interference is to reduce that attraction, which is achieved if $A^k_{ij}(\Delta_i) < 1$.

In Tables 1 and 2, the matrices Q^1 and P^1 give the transition probabilities from the first stage to the second under no and min interference, respectively. Let us have a look at $A^1_{ij}(\Delta_i)$ for $i, j = 1, 2, \ldots, 4$. Clearly, for only seven pairs (i, j), it holds that $A^1_{ij}(\Delta_i) < 1$. Among these are all pairs (i, i). So, here, min interference diminishes the probability of repeating the same offence. However it does not reduce overall criminality.

Next, in Tables 1 and 2, the matrices Q^2 and P^2 give the transition probabilities from the second stage to the third. Now, for only eight pairs (i, j), it holds that $A^2_{ij}(\Delta_i) < 1$. Among these are all pairs $(i, 2)$. So, min interference diminishes the probability of stealing from small RE projects, regardless of

the previous offence. Among these are furthermore three pairs $(i, 4)$. So, for these combinations the probability of stealing from a large RE project diminishes. However, also now, min interference does not reduce overall criminality.

Finally, in Tables 1 and 2, the matrices Q^3 and P^3 give the transition probabilities from the third stage to the fourth. Now, for 15 out of the 16 pairs (i, j), it holds that $A^2_{ij}(\Delta_i) < 1$. So, at last, min interference is successful in reducing overall criminality.

3.1.4. Transition and State Probabilities for Medium and for Max Interference

Clearly, in practice, min interference is the first step to consider. However, when its effects turn out to be disappointing, then it makes sense to consider medium or even strong (so-called max) interference. In our research, we also confronted the interviewees with these two forms of interference. We found out that both have a huge impact already in the transition from first stage to second. Therefore, we confine our analysis to only the transition from first stage to second. Specifically, we take P^{Init} the same as in Table 2 and only examine how the matrix P^1 is changing on the basis of our interviews. Let $P_{med}{}^1$ and $P_{max}{}^1$ denote the matrix of transition probabilities from the first stage to the second stage under medium and strong interference, respectively. From the data analyzed, we extract the matrices given in Table 4.

Table 4. Transition Probabilities from First Stage for Medium and Max Interference.

$$\boldsymbol{P_{med}{}^1} = \begin{Bmatrix} & SPv & SPt & LPv & LPt & R \\ SPv & 0.39 & 0.15 & 0 & 0 & 0.46 \\ SPt & 0.26 & 0.13 & 0.03 & 0.03 & 0.55 \\ LPv & 0 & 0.2 & 0 & 0.2 & 0.6 \\ LPt & 0 & 0.06 & 0.19 & 0.19 & 0.56 \end{Bmatrix} \quad \boldsymbol{P_{max}{}^1} = \begin{Bmatrix} & SPv & SPt & LPv & LPt & R \\ SPv & 0.13 & 0 & 0 & 0 & 0.87 \\ SPt & 0.03 & 0 & 0 & 0 & 0.97 \\ LPv & 0 & 0 & 0 & 0 & 1 \\ LPt & 0 & 0 & 0.06 & 0 & 0.94 \end{Bmatrix}$$

Let the state probabilities in stage k be given by the row vector $\boldsymbol{p_{med,k}}$ and $\boldsymbol{p_{max,k}}$ in case of medium and strong interference, respectively. From the above we find the state probabilities for the second stages (see Table 5).

Table 5. Second Stage State Probabilities for Medium and Strong Interference.

Medium Interference					**Max Interference**				
SPv	*SPt*	*LPv*	*LPt*	*R*	*SPv*	*SPt*	*LPv*	*LPt*	*R*
$\boldsymbol{p_{med,2}} = \boldsymbol{p^{Init}}\,\boldsymbol{P^{Init}}\,\boldsymbol{P_{med}{}^1} =$					$\boldsymbol{p_{max,2}} = \boldsymbol{p^{Init}}\,\boldsymbol{P^{Init}}\,\boldsymbol{P_{max}{}^1} =$				
{ 0.2137	0.1265	0.0528	0.0667	0.5406 }	{ 0.0406	0	0.013	0	0.9465 }

From Table 5 it is evident that both types of interference are effective. In case of medium interference, the majority of offenders (54%) go to rest after their first offence. In case of max interference, nearly all (95%) first offenders go to rest. Those who stay active, vandalize either small RE projects (4%) or large RE projects (1%).

Next, let us examine $A^1_{ij}(\Delta_i)$, the attraction of committing offence j in stage 2 after committing offence i in stage 1 given that offence i has either medium or max level of interference Δ_i.

In Table 1, the matrix $\boldsymbol{Q^1}$ gives the transition probabilities from the first stage to the second under no interference. This matrix has to be compared with the matrices $\boldsymbol{P_{med}{}^1}$ and $\boldsymbol{P_{max}{}^1}$ from Table 4, which give the transition probabilities from the first stage to the second stage under medium and max interference, respectively.

Comparing $\boldsymbol{Q^1}$ with $\boldsymbol{P_{med}{}^1}$ tells us that for 14 pairs (i, j), it holds that $A^1_{ij}(\Delta_i) < 1$. So, under medium interference, almost all transitions between first offences and second offences are less attractive than under no interference.

Comparing $\boldsymbol{Q^1}$ with $\boldsymbol{P_{max}}^{\mathbf{1}}$ shows that $A_{ij}^{1}(\Delta_i) < 1$ for all all pairs (i, j), So, under max interference, no criminal transitions from stage 1 to stage 2 gain any attraction. Earlier, we deemed it plausible to expect that the attraction $A_{ij}^{k}(\Delta_i)$ is non-increasing with increasing level of interference Δ_i. Let us test this hypothesis for $k = 1$. Using the matrices $\boldsymbol{Q^1}$ and $\boldsymbol{P^1}$ from Tables 1 and 2 and $\boldsymbol{P_{med}}^{1}$ and $\boldsymbol{P_{max}}^{\mathbf{1}}$ from Table 4, we find that for 11 out of the 16 pairs (i, j), the attraction $A_{ij}^{k}(\Delta_i)$ is indeed a non-increasing function of Δ_i.

3.2. Dependence on the Initial Stage (Approach Generalization)

As discussed in Section 3.1.1, our data analysis yields the following values for the probabilities transitioning from initial rest [*I*] to any of the three instigators (Government Inequality [GI], Crime to Survive[SU], Sabotage[SA]):

$$\boldsymbol{p^{Init}} = (p_{I\_GI},\ p_{I\_SU},\ p_{I\_SA}) = \left\{ \begin{array}{ccc} 0.5556 & 0.3611 & 0.0833 \end{array} \right\}$$

The state probabilities for no interference and for least security interference resulting from this initial stage are given in Table 3. One may wonder how the career of a criminal may evolve from a different initial stage. To illustrate this, let us consider two cases. In case (i) we assume that Government Inequality has been reduced by political reforms, whereas Crime to Survive and Sabotage keep the same ratio. Specifically, we choose as initial stage $\boldsymbol{p^{Init,1}} = \left\{ \begin{array}{ccc} 0.4 & 0.4875 & 0.1125 \end{array} \right\}$. In case (ii) we assume that Crime to Survive is increasing because of poor living conditions, whereas Government Inequality and Sabotage keep the same ratio. Specifically, we choose as initial stage $\boldsymbol{p^{Init,2}} = \left\{ \begin{array}{ccc} 0.3478 & 0.6 & 0.0522 \end{array} \right\}$. Table 6 shows the corresponding state probabilities in the first and in the fourth stage for no interference. The first stage shows minor differences in the probability values. In the fourth stage, it is hardly noticeable that the three criminal careers arose from different initial stages. Similar behavior is found for all degrees of interference. Although convergence of the state probabilities is to be expected, it is surprising that the initial probabilities lose their character this soon. So, despite of the initial motivation of the criminal, the expected career pattern evolves in a predictable way.

Table 6. State Probabilities with different Initial Stage Probabilities for no Interference.

	Motivation			**First Stage**				**Fourth Stage**				
	GI	**SU**	**SA**	**SPv**	**SPt**	**LPv**	**LPt**	**SPv**	**SPt**	**LPv**	**LPt**	**R**
Base Case	0.5556	0.3611	0.083	0.1944	0.5138	0.0694	0.2223	0.0484	0.0279	0.1172	0.0825	0.7236
Case (i)	0.4	0.4875	0.113	0.1837	0.5712	0.05	0.1951	0.0488	0.028	0.1167	0.0817	0.7245
Case (ii)	0.3478	0.6	0.052	0.1217	0.638	0.0435	0.1968	0.0486	0.028	0.1165	0.0819	0.7246

3.3. Recommended Interferences per Project Offence

In the previous analysis we assumed all states to have equal interference. In practice, this will be different. Obviously, large security differences between nearby projects are not recommendable, since word of mouth will direct the offenders to those projects that are least protected. In this section, let us determine adequate interferences per project offence whilst taking into account the rigorously executed analysis.

Section 3.1.2 shows that min interference will only be effective in the long run. So on a project base, the choice will be between med and max interference. Incidentally, this choice has the advantage of diminishing differences between applied interference

As discussed in Section 3.1, we asked the participants of the study to rank the interferences based on difficulty (See Table 7).

Table 7. Ranking of Interferences.

Level	Interference Type	Selections	Probability of Rest or Exit at Stage 1
Max	SS	57%	95%
	TS	7%	
	HS	36%	
Med	SS	28%	54%
	TS	39%	
	HS	33%	
Min	SS	17%	15%
	TS	24%	
	HS	59%	

Combining our findings from the previous sections with Table 7, we recommend the following interference types:

- SPv: for no, min and medium (overall) interference, vandalizing small RE projects is stable over the stages and attracts roughly 20%. With max interference this drops to 4% in stage 2. So, we recommend max interference. To achieve this, we aim for SS followed by HS (see Table 7).
- SPt: stealing from a small RE project is popular in the first stage (52%) and decreases monotonically as stages go on. We recommend medium interference, which reduces the popularity from 35% to 13% in stage 2. To achieve this, we aim for TS followed by HS.
- LPv: for no to min interference, vandalizing large RE projects increases in popularity over the stages from 7% in stage 1 to 16% and 20%, respectively, in stage 3. Medium interference will reduce this to only 5% in stage 2. To achieve this, we aim for TS followed by HS.
- LPt: for no to min interference, in the third stage, stealing from a large RE project is preferred by 39% and 35%, respectively. In the first stage, this was only 22% and 21%. With max interference this drops to 0% in stage 2. So, we recommend max interference. To achieve this, we aim for SS followed by HS.

4. Conclusions

Sub-Saharan Africa's development is dependent heavily on energy provision and access. The region currently suffers from lack of energy and although various RE development projects have been implemented, the advantages of these projects are yet to be felt on a wide scale. Nonetheless, the region possesses the opportunity to move directly in the era of renewable energy rather than investing in energy generation methods that could be detrimental to the planet. Excluding the funding, there exists a long list of reasons as to why energy projects in SSA fail. This includes management, maintenance, nepotism, disturbances such as theft and vandalism etc. For Sub-Saharan Africa to thrive in any sector the issues of living and planning sustainably must be addressed and this includes planning against disturbances such as theft and vandalism to energy projects in the region. History should be learnt from, as can be seen in various countries around the region where energy infrastructures have been vandalized and purloined during riots of government inequality and for the sake of survival. As such, to avoid a repetition of the past, these issues must be considered prior to the implementation of any RE development project.

In our study, we engaged directly with participants from the region of Sub-Saharan Africa to generate data for the analysis that we present. Throughout the study we carefully analyzed the impacts that disturbances such as theft and vandalism have on the future of RE development projects in SSA whilst directly exploring the impact on both small and large projects. Based on the dialogues, analysis, and practical experiences the following findings and recommendations are provided:

- The implementation of interferences is important to guarantee the sustainability of RE development projects in Sub-Saharan Africa. However, for its successful accomplishment, it is

important that the local communities are involved as stakeholders prior to the implementation of the project and after.

- Large scale projects should combine multiple interference approaches. However, it is advisable that energy projects are broken down into the smallest subsets possible to guarantee their sustainability. More importantly, solving Africa's energy problems is more feasible via the decentralization of energy generation.
- The implementation of large RE development projects isn't advisable. However, in cases where this is the only feasible option—after exhaustive planning and studies have been carried out—*technical security and human security* are the most effective interference to consider. This is also the case for projects implemented in locations without surrounding habitants as is the characteristic of a large RE project.
- Small scale projects should utilize societal security (SS) as this is considered the most effective class of interference against the persistent threat of vandalizing. However, the local community must be trained in the aspect of maintenance of the systems. More so, a knowledge database must be made available for the local community to learn from best practices that would support the overall sustainability of these projects.
- Individuals not successful in attempts to purloin RE infrastructures from project sites are more likely to deviate into vandalization. However, this is mostly seen in cases where the primary instigator is government inequality (GI). On the other hand, people instigated by survival (SU) are only focused on the theft aspect. When theft is not possible, they are likely to change locations or return to the same project.
- Though technical security (TS) is most widely utilized in western implemented projects, this is a totally different case in Sub-Saharan Africa, since the utilization of TS as a standalone option in RE development projects would more likely lead to vandalization of the project.

Our study looks at the analysis of theft and vandalism on RE development project and how this could affect the sustainability of these projects in the future. By considering data from individuals in the region and analyzing the state of energy infrastructures in the countries we present the necessary analysis and findings required. Furthermore, since this study is to the best our knowledge the first study of its kind to focus on the impact of disturbances towards the sustainability of RE development projects, it is therefore important that financing government and implementing organization consider disturbances such as theft and vandalism prior to the implementation of RE development projects in Sub-Saharan Africa for these projects to be sustainable.

This paper analyzes the impact of disturbances such as theft and vandalism on RE development projects in SSA. As in any research, limitations present themselves. One limitation experienced in our study is funding. As such we were able to only utilize 144 respondents. A larger number would have enabled us to calibrate an extended Markov model in which we incorporate the notion of 'success' and 'failure'. In addition, it would be interesting to follow the actual criminal career of the 21% of actual offenders and compare this with our model. Although we presented implementable interferences, it may be worthwhile to measure the impact of other types of interferences on corresponding projects that may exist in the future. Financial aspects were out of scope in our research. However, in future research it may be interesting to perform a break-even analysis into the financial consequences of the interferences considered. Finally, we believe that our multi-stage Markov approach is generally applicable to any situation dominated by processes where maturity of human beings as well as reaction to exterior stimuli is essential.

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