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Editorial Note

It is with great pleasure that we present the first issue of the Volume three of the *Interdisciplinary Journal of Papua New Guinea University of Technology* (IJPNGUoT). This journal was established with a clear purpose to provide a platform for rigorous scholarly work that crosses traditional disciplinary boundaries. Research that addresses real-world challenges rarely fits neatly within a single field, and we believe some of the most valuable insights emerge at the intersections of engineering, science, social inquiry, and applied technology.

In this issue, our contributors continue that tradition. The papers gathered here reflect the diverse intellectual strengths of our university community and our growing network of collaborators. Each submission has undergone careful peer review, and we are grateful to the reviewers whose expertise and diligence uphold the standards of this publication.

We extend our sincere gratitude to the authors who entrusted their work to this journal. Academic publishing demands patience, revision, and a willingness to engage with critical feedback—qualities our contributors have demonstrated throughout the editorial process.

As we release this issue, we also look ahead. We encourage researchers across Papua New Guinea and the wider regions of the globe to consider this journal as a home for work that bridges disciplines and engages with the pressing questions of our time. Whether your research addresses technological innovation, environmental sustainability, public health, education, or the social dimensions of development, we welcome submissions that meet our standards of rigour and relevance.

We hope the works presented here spark new ideas, informs practice, and contributes to the ongoing conversation among scholars committed to knowledge that matters.

I am delighted to welcome Dr Kamalakanta Muduli, as the new Executive Editor of the IJPNGUoT.

Prof Jojo Panakal John
Editor in Chief

Executive Editor's message

The Interdisciplinary Journal of Papua New Guinea University of Technology (IJPNGUoT) is very proud to publish the issue 1 of Volume 3. This issue will feature nine different and thought-provoking articles that all contribute to the journal's goal of developing interdisciplinary scholastic work relevant to Papua New Guinea and the rest of the Pacific. The research works included in the issue reflect the wide range of research carried out to tackle PNG's national and global challenges. The articles included in this issue advocate a theme: seeking solutions that are practical, locally-focused, and interdisciplinary in nature to the multifaceted challenges of PNG and Asia Pacific. The findings of these studies offer noteworthy contributions to the learning for practitioners, policy makers, communities and researchers across a diverse range of fields including food security, industrial efficiency, youth development, environmental sustainability, and educational transformation.

The highlights of the issue are as presented below.

The first article underscores the need for science-based solutions that are adapted to the local context and are effective for emerging pest threats. This research revealed that virulence of local Metarhizium anisopliae isolates against coconut rhinoceros beetle could be an important biological control strategies for biosecurity of the coconut and oil palm industries in PNG. The study on engineering equipment failures and inventory management in PNG's mining sector is an interesting combination of predictive maintenance and inventory intelligence which is presented in second article. The research paves the way for leveraging technological advancements and sensor-based analytics to cut down on downtime and enhance operational efficiency in remote mining settings. The third article on integrated natural and socio-economic capital systems is a timely reminder of energy sustainability and climate resilience in the Asia-Pacific region. A critical analysis of employment opportunities for out-of-school youth in PNG presented in fourth article, encourages policy makers to transcend the rhetoric and provide positive avenues for youth empowerment and engagement in development. The short communication on guerrilla marketing for island sustainability presented in fifth article advocates new ideas, techniques and strategies for raising awareness and changing behaviour in relation to the environment, using an innovative and low-cost method and illustrates the importance of community-based innovation. Comparative research on coffee marketing decisions among smallholder growers in Morobe Province presented in sixth article, offers insightful findings on cooperative involvement, bargaining practices and income security among the farmers. There are two articles seventh and ninth, that discuss issues related to physics teaching in PNG, including cultural intelligence across regions, status of ICT in school and teaching platforms in Grades 11 and 12. All of these studies highlight the importance of culturally responsive and technologically inclusive education systems. The study of the photooxygenation of furfural using solar and visible light reported in eighth article shows innovative routes to production of valuable commodity chemicals from agricultural waste, which is an emerging area of the utilization of renewable biomass.

The editorial board would like to express its heartfelt gratitude to all the authors for their scholarly work, reviewers for their critical evaluations and readers for their continued patronage of IJPNGUoT.

Dr Kamalakanta Muduli
Executive Editor

TABLE OF CONTENTS

Virulence of Indigenous Isolates of *Metarhizium anisopliae* to Life Stages of the Coconut Rhinoceros Beetle (Coleoptera: Scarabaeidae: Dynastinae) in Papua New Guinea

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Abstract: Coconut, *Cocos nucifera* L., is important crop in PNG and has been challenged with the invasion of pests. The coconut rhinoceros beetle (CRB), *Oryctes rhinoceros* is a serious pest to coconut and threatens the oil palm industry. In recent years, CRB-G biotype evaded the existing biological control agent *Oryctes nudivirus* introduced into the Pacific Islands, in the 1960s. Using pheromone trapping and visual rating, this study assessed population and damage by CRB in Markham Valley, Morobe province; and investigated the virulence of two indigenous isolates of *Metarhizium anisopliae* on CRB life stages by topical inoculation under laboratory conditions. Moderate damage levels was recorded on coconut palms in Daeng villages. Mixed sex CRB were caught in the 3 seasons of trapping, with more males trapped than females at the sites. Laboratory tests revealed that the two isolates varied in germination, time to sporulation on cadaver and virulence. Larval and adult CRB survival decreased by 20% through time when inoculated with the spores of *M. anisopliae*. At 21 and 25 DAI, isolate Ma2 caused high mortality at the shortest time on the larval (82%) and adult (80%), respectively. Isolate Ma2 has the potential as a microbial control agent against CRB. Further evaluation is required for high spore dosage application, spore transmissibility, and 'lure-and-kill' strategy under field conditions.

Keywords: *Oryctes rhinoceros*, *Metarhizium anisopliae*, coconut, pheromone trapping, Papua New Guinea

1. INTRODUCTION

Coconut (*Cocos nucifera* L.) is a subsistence crop, commonly grown around the coastal region of Papua New Guinea (PNG). Yet it is an old industry in PNG that once contributed greatly to the country's economy and subsequent growth and development (Hanson et al, 1998). However, copra production declined over the years due to several factors including fall in global prices that led to abandoning of plantations and infestations by insect pests and diseases, including rhinoceros beetles (KIK Report, 2016). Population of the coconut rhinoceros beetle (CRB), *Oryctes rhinoceros*, had been detected in Guam in 2009 (Marshall et al, 2017). This CRB population was reported to have evaded the biological control agent, *Oryctes nudivirus* (*OrV*); a virus introduced in the 1980s into the Pacific islands, including PNG. Due to its evasion, molecular studies by Marshall et al (2017) had led to the discovery of a biotype; referred to as the CRB Guam biotype (CRB-G). This biotype was detected in PNG in 2010-2012 National CRB Survey (Ero et al, 2016). The development of resistance by CRB-G to *OrV* maybe possibly due to sole reliance of a single biocontrol agent in the wild, and modifications of female oviposition behaviour (Manlet et al, 2018). CRB-G, unlike the Samoan biotype (CRB-S) successfully suppressed by *OrV*, is the most destructive pest to coconut and poses a threat to the oil palm industry (Ero et al, 2016; Jackson et al, 2020). Coconut rhinoceros beetle infestations on coconuts results in up to 50% palm mortality and significant losses in some islands in the Pacific including Samoa and PNG (Jackson et al, 2020), however, these recorded losses may have increased in recent times. In PNG, neglected coconut gardens in the vicinity of commercial oil

palm plantations may act as CRB reservoir for future infestations on oil palm (*Elaeis guineensis* L.), as it is evident in recent times that CRB is slowly but steadily becoming an oil palm pest as well (PNGOPRA, 2014). Heavy infestations on coconut and oil palm have profound effects on rural communities that depend entirely on these crops because they are the major income generators for these coastal communities.

Entomopathogenic fungi (EPF) such as *Metarhizium* spp. are naturally occurring fungi successfully utilized as biological control agents against insect pests and plant disease antagonists (Ramle et al, 2009; Rajula et al, 2021). *Metarhizium* is naturally associated with CRB and related dynastid beetles (Bedford, 1980; 2013) and was first discovered to infect larvae and adult CRB in breeding sites in coconut and oil palm debris. Due to this natural association between the fungus and CRB and failure of *OrV* to regulate wild populations of CRB in general, the search for indigenous strains of *Metarhizium* is essential for their utilization as potential biological control agents. Indigenous strains of EPF are more promising for the management of indigenous pest species, which are proven effective on CRB as in Malaysia and the Solomon Islands (Ramle et al, 2007; 2009; 2011). At present, there is limited knowledge into using *Metarhizium* and other EPF for CRB control although related species of scarabs have been reportedly susceptible to this entomopathogenic fungus (Theunis & Aloal'i, 1998; Moxon, 2008). This study was conducted to assess the CRB damage levels on coconuts and oil palm in the Markham Valley and investigate the efficacy of a strain of commercially-formulated *M. anisopliae* and indigenous strains of *M. anisopliae* on life stages of CRB.

2. MATERIALS AND METHODS

2.1 CRB infestation/damage and population surveys

This exercise was carried out to determine the levels of CRB infestations, purposely for trapping and collection of adult CRB for laboratory studies. Between 2018 and 2019, field observations were conducted in the Markham Valley for typical V-shaped cuts on fronds of coconut palms following assessments by Ero et al (2016). Subsequently, local farmers and field officers of Markham Farms Ltd were interviewed regarding damage of palms by the CRB on coconut and oil palm, respectively. Trapping devices were stationed at 100-150 m apart in Daeng village (GPS; 6°23′09″S, 146°18′23″E), Mutzing, Markham District. Pheromone trap is produced by male CRBs and is a common control technique in Malaysian oil palm plantations (Manjer et al., 2014; Kamarudin et al., 2007) and is now being incorporated into the control measures of CRB in the Pacific including PNG.

Pheromone lure (ethyl-4-methyl loctanoate P046-Lure, ChemTica Internacional, Costa Rica) was incorporated into a trapping device, consisting of 15 cm Ø × 3 m PVC pipe and a collection bucket at the bottom following Ero et al (2016) with modifications. Two 30 cm^2 holes cut out on opposite sides of the pipe just below the edge of the pipe and the holes were not parallel to each other but 10 cm apart (Fig 1). Tie wire was wired across the diameter right above the cut-out holes and a lure sachet was suspended. This method was adopted because it is inexpensive with good precision. Further field surveys were conducted in the village in a mixed crop field (56,750.88 m^2) containing over ninety coconut palm trees planted in no specific order, with understory occupied by 60 cocoa trees, some banana trees and shade trees. The type of defoliation observed gave the basis for infestation level and it was labeled accordingly as no defoliation, light defoliation (1-10% damage), moderate (11-30%) and severe (> 30%).

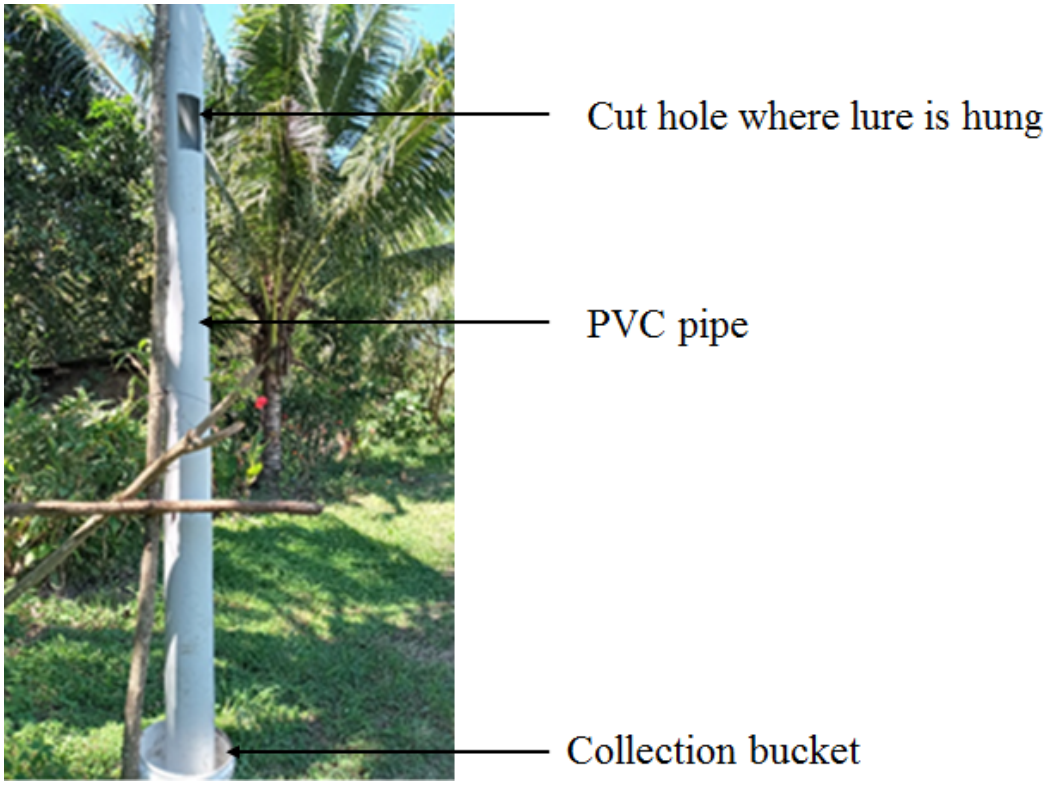

Figure 1. CRB lure setup with PVC and collecton bucket. CRB attracted to the lure fly into the cut holes on each side and fall through the PVC pipe into the bucket.

A rain gauge was also stationed in the Daeng Village to determine rainfall at the course of the CRB trapping. Traps were monitored every 5 days for 7 months. Caught adult CRB in the collection bucket were first counted then sexed using developed keys for distinguishing sexes (Bedford, 2013), placed in clear plastic cages and brought to the laboratory. Additionally, dead but standing coconut palms were felled and searched for incidence of CRB larvae.

2.2 Test insects rearing

CRB larvae (1st – 2nd instar) were field-collected in debris heaps and rotten tree stumps, and reared in captivity to 3rd or 4th instar. Larvae were separated from other scarab species larvae using identification keys (Beaudoin-Ollivier et al, 2000). A mixture of cattle dung and sawdust at a 1:2 ratio was added into each rearing cage (39 cm × 30 cm × 25.5 cm, L×W×H) to 15 cm depth. Adult CRB beetles were caught from the wild using a pheromone previously described. The insects were brought to the laboratory and reared in captivity in 15 L clear plastic boxes, 4 beetles (mixed sex) to a box. Each box had dices of ripe Cavendish banana and apple as food source and replaced once every 5 days (Bedford, 2014). Rearing cages were kept at room temperature (26 ± 2 ºC) in the laboratory, Unitech Biotechnology Centre.

2.3 Source of fungi

The details of *Metarhizium* strains used in this study are provided in Table 1. Isolates Ma1 and Ma2 were identified as *M. anisopliae* using ITS primers (Gurr et al, 2022). Spores from glycerin-preserved agar slants of the isolates were cultured either on fresh Sabouraud dextrose agar with 5% yeast (SDAY) or potato dextrose agar (PDA) media plates to facilitate fungal growth. A commercial-formulated strain of *M. anisopliae* (Oryx-X®, FGV Agri Services, Malaysia) used for CRB control in Malaysia, was donated by Dr Mark Ero (PNGOPRA, PNG) for comparison against the indigenous isolates; however, due to germination and growth failure in culture plates after many attempts, it was not included in this study.

Table 1. Source of *Metarhizium anisopliae* isolates tested against CRB life stages.

Isolate	Source	Locality	Elevation
Ma1	Baited from soil samples collected from sweetpotato gardens	Ruinga, Jiwaka province,	5.8691° S, 144.6973° E, 1602 m asl
Ma2	Baited from soil samples collected from sweetpotato gardens	Asaro Valley, Eastern Highlands province	6.5862° S, 145.6690° E, 1570 m asl

2.4 Laboratory studies

Experiment 1: CRB larval bioassay

A spore suspension was prepared in 0.5% Tween 20® solution to challenge CRB larvae. Conidia were harvested from 16-day old cultures; spore counts and dilution was conducted with Neubauer haemocytometer and concentrations adjusted to 5×10^8 conidia/ml. Five to 6 CRB larvae were inoculated by immersing larva individually into the spore suspension for 2-3 s (Ondiaka et al, 2008; Dotaona et al, 2015). Inoculated larva was placed on a paper tissue for 30-60 s to remove excess suspension on the larva. Only 3rd to 4th instar larvae were used in the study. Larvae for the control treatment were immersed in 0.5% Tween 20® solution. Inoculated larvae were placed individually in disposable clear plastic lunch boxes (14 cm × 11 cm × 6 cm), containing a mixture of cow dung-sawdust as a food source. Altogether there were 3 treatments replicated 6 times in a completely randomized design. Observations were made on 7, 14 and 21 days after inoculation (DAI). Larvae that were killed (or cadaver) at 7, 14 and 21 DAI were removed from the treatment containers and were lightly rinsed with sterile distilled water (dH_2O), soaked in 0.05% NaOCl and a 60 s soak in 70% ethanol for surface sterilisation. Sterilized cadavers were finally rinsed with dH_2O three times then air dried on paper towels. A moistened Whatman® No. 1 filter paper (80 mm Ø) was placed into a 250 ml white foam cup and cadaver placed on it. Cups containing cadavers were sealed and incubated at dark at room temperature (26 ± 2°C) to allow mycosis and sporulation.

Experiment 2: Adult CRB bioassay

Bioassays on wild-collected CRB were conducted between June and August 2023. Adult CRB were trapped in Markham Valley using the previously described trapping procedure. At the bioassay, adult CRB were separated from the rearing boxes and starved for 24 h. Similar bioassay procedures as in Experiment 1 were followed. Spore viability test was carried out for the two *Metarhizium* isolates prior to preparation of the spore suspensions. Adult CRB beetle was inoculated by immersing the insect into a spore suspension for 3-4 s. Control beetles were immersed in 0.05% Triton X-100 solution. Ten beetles were inoculated per replicate, and each *Metarhizium* isolate was replicated 4 times. Inoculated beetle was placed on a tissue paper for 60 s to absorb excess water and placed in disposable clear plastic lunch box (14 cm × 11 cm × 6 cm) with cut lid (2 cm × 1 cm opening) for ventilation. The lunch box contained a 50 g diced ripe banana, was subsequently replaced after 3 days by a 50 g diced apple. Boxes were placed in the dark at room temperature (26 ± 2°C) and positions changed every 3 days. Beetle mortality was recorded daily. Beetles motionless and showing stiff legs were considered as dead, removed from the rearing box and placed on moistened filter paper in a 250 ml foam cup, sealed and incubated to encourage mycosis and sporulation. Time to fungal mycosis on dead beetle was also recorded. The bioassay was repeated after two months.

Data analysis

Data on CRB infestation survey and the laboratory bioassays were first collated in Microsoft Excel (2010). Percent damage was calculated by the number of coconut palms showing symptoms of CRB infestation over the total number of coconuts surveyed.

For the CRB trapping, the number of beetles from monthly traps in each year and sex ratios were square root transformed [$\sqrt{(x + 0.5)}$] and inverse sine transformed, respectively, to achieve approximate normality (Zar, 1974; Wilson & Hardy, 2002). Sex ratio data were pooled by month and one-way analysis of variance (ANOVA) performed. A two-way ANOVA was used to separate the effects of months and seasons (years) on beetle catches.

For the analysis of spore germination data, one-way ANOVA was used. Mann-Whitney test (Zar, 1974), a non-parametric test, was used to analyze time to sporulation.

For experiments 1 and 2, the data on repeated bioassays were combined as no significant interactions were detected between effects of treatment and the repeat times. If ANOVA indicated a significance *F* value, Fisher's least significance difference (LSD) was used to compare treatment means at 5% significance level. Beetle catches (sex ratios) and spore germination data analyses were performed in SPSS for Windows (Version 26.0, Armonk, NY) and bioassay data analyses performed in Genstat 14th Edition (VSN International Ltd., UK).

3. RESULTS

3.1 CRB infestation survey and trapping

Ninety sampled palms of the total 120 coconut palms showed 30% of the trees have fronds with V-shaped damage typical of CRB feeding, and 20% of the physically assessed trees that were simultaneously observed when assessing damage on fronds have both old and new boreholes at the frond base. No CRB was reported in the oil palm plantations, however, infestations were observed mainly on coconut palms at the vicinity of oil palm blocks. The coconut palms in Daeng village were subsequently classified as moderately damaged (15%).

The pheromone traps attracted mixed sex beetles with significantly high beetle catches ($F_{6,12} = 3.527$, $P < 0.05$) in June-July during the 3 years (Fig 2A). Beetle catches between seasons were not statistically different ($F_{2,12} = 0.157$, $P = 0.857$), however, high proportions of up to 80% ($F_{1,12} = 9.05$, $P < 0.05$) male CRB were caught at the trapping period. As observed in this time of the year, minimal rainfalls (Fig 2B) were received, up to a monthly average of 47 mm.

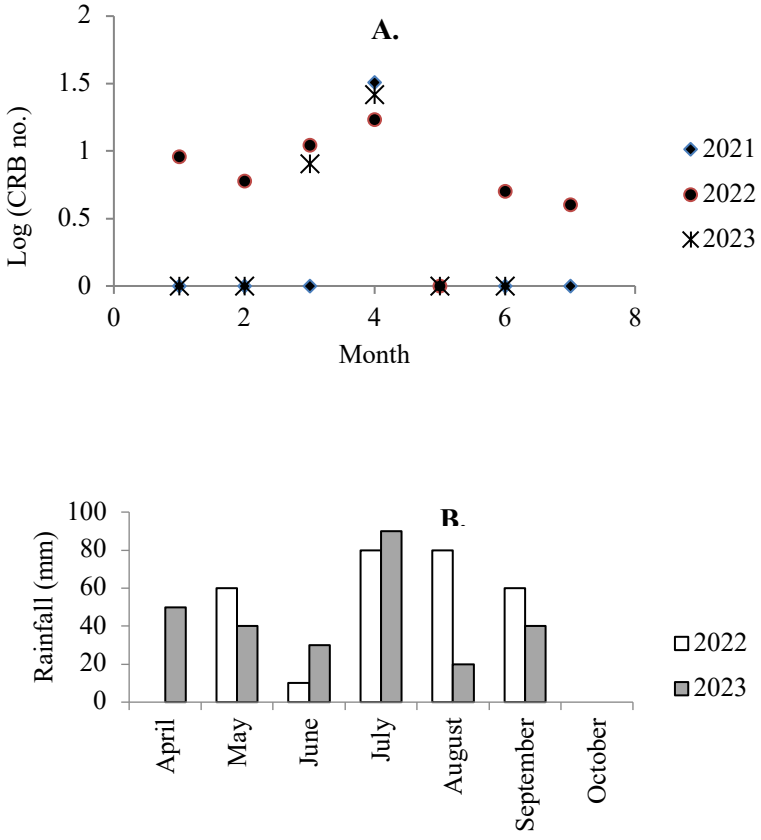

Figure 2. CRB adult catches (A) using aggregate pheromone and, (B) rainfall received in two years in experimental site, Daeng village.

Average catch and rainfall in 3 years was regressed to determine if any relationship exists. Regression showed a statistically significant relationship between the rainfall and beetle catch ($R^2 = 0.67$, $F_{1,5} = 10.08$, $P < 0.05$) (Fig 3).

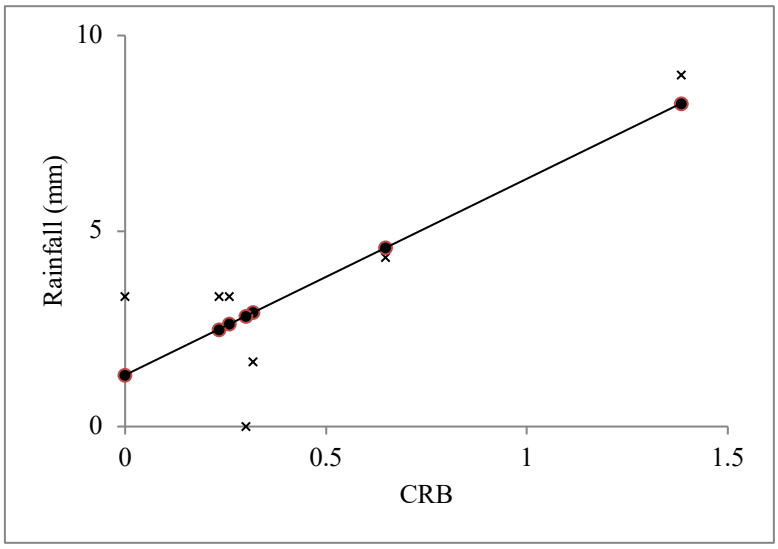

Figure 3. Relationship between rainfall and CRB catch with regression best fit line (Y = 5.02*x* + 1.317).

3.2 Laboratory studies

Laboratory bioassays to test the virulence of indigenous *M. anisopliae* on different life stages of CRB are presented Figures 4 and 5. Inoculated CRB larvae and adult with *M. anisopliae* isolates reduced mean survival. In the larval stage, death was initiated before 5 DAI for the experimental treatments and after 10 DAI for the control treatment (Fig 4). The median lethal time (LT_{50}) for the two isolates at conidia dosage 5×10^8 conidia/ml was reached between 18 and 19 DAI.

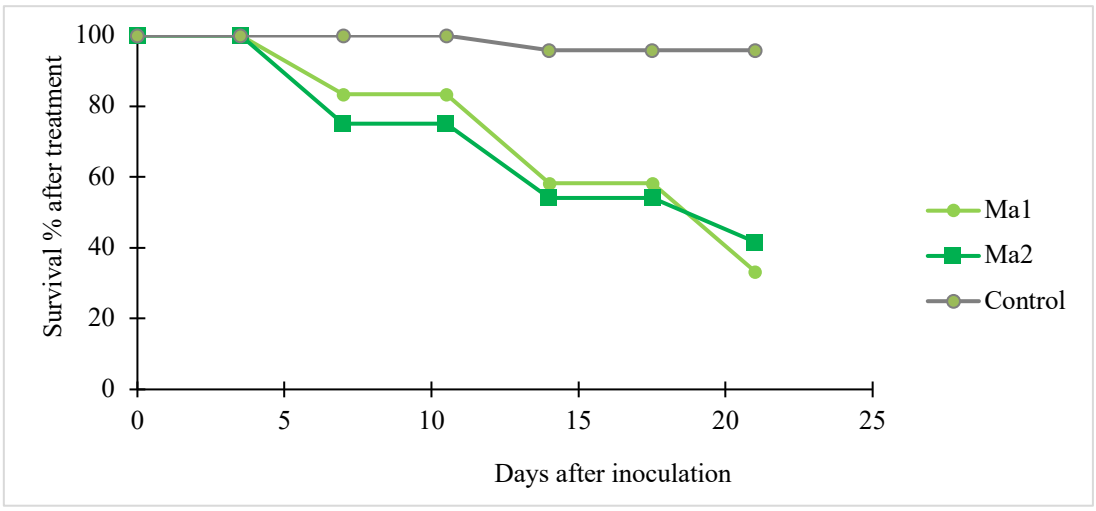

Figure 4. Mean survival times of CRB larvae (3rd/4th instar) over time after inoculation with isolates of *M. anisopliae*.

Despite having similar spore germination, rapid sporulation of isolate Ma1 was observed on the larval cadavers, compared to isolate Ma2 (Table 2). At 21 DAI, isolate Ma2 caused the highest larval mortality (Table 2). The mean survival in inoculated adult CRB likewise declined over the 25-day exposure, compared to the control treatment. Beetle deaths occurred at 7 DAI in inoculated adult CRB and LT_{50} for isolate Ma2 was reached at 17 DAI (Fig 5). Time to sporulation on the incubated beetle cadaver was rapid in isolate Ma1, taking 6 days, than in Ma2. However, after 25-day exposure, Ma2 of the two isolates caused the highest beetle mortality (Table 3).

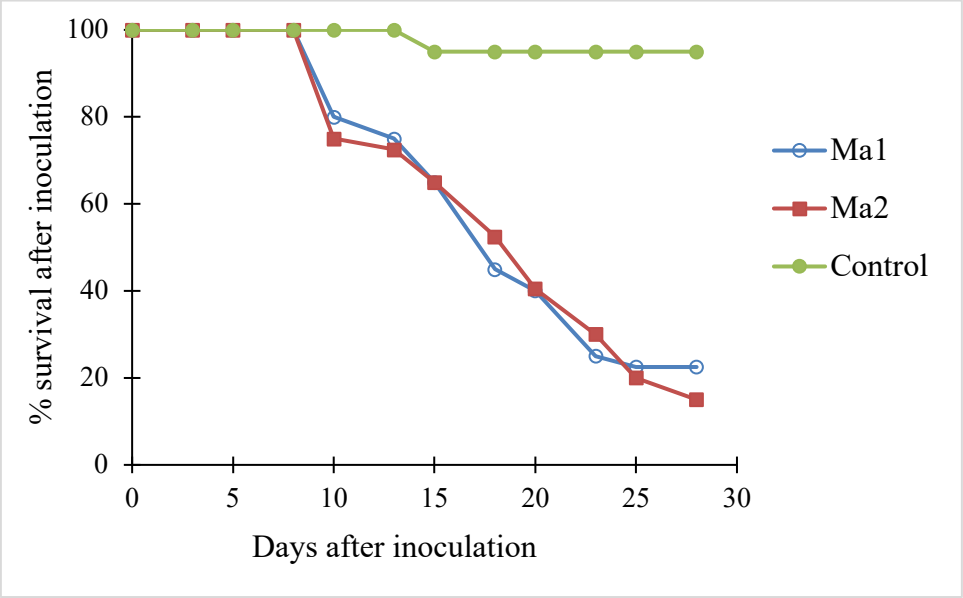

Figure 5. Mean survival times of adult CRB over time after inoculation with isolates of *M. anisopliae*.

Table 2. Corrected mortality of larvae CRB after inoculation with *Metarhizium anisopliae* isolates and incubation at 26±2°C. DAI, days after inoculation. *n* = 10 larvae per replicate.

Isolate/treatment	% spore germination	Time (days) to sporulation	Corrected % mortality		
			7 DAI	14 DAI	21 DAI
Ma1	80 ± 2a*	5.5 ± 1.1a[1]	17a†	45a†	70a†
Ma2	86 ± 3a	7.4 ± 1.2b	20a	50b	82b
Control	-	-	0b	6c	9c

*Means with the same letter within a column do not differ significantly at $P > 0.05$ (ANOVA). [1]Means with the same letter within a column do not differ significantly at $P < 0.05$ (Mann-Whitney test). †Means with the same letter within a column do not differ significantly at $P < 0.05$ (ANOVA, LSD test).

Table 3. Corrected mortality of adult CRB after inoculation with *Metarhizium anisopliae* isolates and incubation at 26±2°C. DAI, days after inoculation. *n* = 10 beetles per replicate.

Isolate/treatment	% spore germination	Time (days) to sporulation	Corrected % mortality	
			15 DAI	25 DAI
Ma1	78 ± 4a*	6.2 ± 0.1a†	50a[1]	74a[1]
Ma2	89 ± 3b	7.5 ± 0.5b	39b	80b
Control	-	-	0c	5c

*Means with the same letter within a column do not differ significantly at $P > 0.05$. †Means with the same letter within a column do not differ significantly at $P < 0.05$ (Mann-Whitney test). [1]Means with the same letter within a column do not differ significantly at $P < 0.05$ (ANOVA, LSD test).

4. DISCUSSION

CRB is an invasive insect to cultivated and ornamental palms, and severe infestations have been reported elsewhere in PNG. In our survey in the Daeng village, Markham Valley, symptoms of CRB infestations were similar to descriptions reported in Port Moresby and offshore islands including New Britain and New Ireland (Ero et al, 2016). Moderate infestations have been recorded on coconut palms but rarely on oil palm. One reason for rare infestations on oil palm was due to the fact that Markham Farms practiced crop sanitation by removing old stumps which attract CRB breeding, and regular monitoring by using pheromone lures incorporated with insecticide to lure and kill. Early larval instars (1^{st} – 2^{nd} instar) were recovered from rotting felled coconut palms, within the trunk of dead standing palms and beetle-infested young palms (2-3 years old). It is evident that female CRB oviposits within the bark of dead standing trunk, which is rarely reported. Since the traps had been incorporated with aggregation pheromone, mixed sex beetles were caught; however, we observed higher male:female ratio compared to other studies reporting lower male:female sex ratio (Oehlschlager, 2007; Manjeri et al, 2014). Several studies (e.g. Kamarudin & Wahid, 2004; Aidoo et al, 2022) reported monthly rainfall above 20 mm to stimulate the flight movement of CRB in search for breeding sites, hence increase in trapped beetles. Our findings showed that in areas where regular dry spells occur, as is the case of Markham Valley, prolonged dry spells followed by minimal rains undoubtedly encouraged CRB flight movement. Prolonged wet seasons, on the other hand, are unfavourable to CRB survival, as these cause high beetle drowning at mating and female oviposition, thus high mortality (L. Kuniata, *pers. comm*., Ramu Agri Industries).

The two *M. anisopliae* isolates tested here were sourced from the soil with histories of sweetpotato cultivation in the highlands of PNG, and these isolates were highly virulent to sweetpotato weevils (*Cylas formicarius* and *Euscepes postfasciatus*, Coleoptera) in previous studies (Gurr et al, 2022). In many cases, *M. anisopliae* isolates maintained considerable spore viability, virulence and host specificity to insect species of the same order or of the same genus,. For instance, the isolate of *M. anisopliae* sourced from adult taro beetle (*Papuana woodlarkiana*) in PNG exhibited high virulence to another species of taro beetle (*P. uninodis*) in Fiji (Theunis & Aloali'i, 1998)), and *M. lepidiotae* that infects *Lepidiota* beetles (Coleoptera) and other scarab species in Australia and PNG (Driver et al, 2000; Bischoff et al, 2009). Certain isolates may have low host specificity as those reported to cause high mortality on insect species of different orders; fruit flies (Diptera) (Dimbi et al, 2003) as well as sweetpotato weevil (Coleoptera) (Ondiaka et al, 2008). Our study showed that one of the two *M. anisopliae* isolates (Ma2) was more virulent, however, the two isolates exhibited some host specificity on Coleoptera species at this stage. The isolates varied significantly in spore germination, virulence and time to sporulation on cadaver. The relationship of age of wild-caught CRB and sex type to fungal infection were not established in this study. While isolate Ma1 exhibited high % germination rate and fast sporulation on cadaver, which are desirable traits for fungal transmission and possible natural epizootics, it caused low mortality on CRB larval and adult stage in comparison to isolate Ma2. We were unable to test their efficacy at multi-dose spore concentration and transmission studies from infected to healthy individuals (Dotaona et al, 2015; Khun et al, 2020). The two isolates are unique; sourced from the high altitudes and are virulent on an insect host in the lowlands of PNG, hence may be considered as having altitudinal plasticity. Future field studies will require testing of higher spore concentrations of isolate Ma2, its efficacy and spore transmissibility, and 'lure-and-kill' strategy by incorporating Ma2 infective spores in the trapping system.

ACKNOWLEDGEMENTS

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Engineering Equipment Failures and Inventory Management Shifts Statistical Insights from Papua New Guinea's Mining Sector

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Abstract: The operation of surface mines in Papua New Guinea (PNG) is associated with the intense mechanical loading, remote logistics, and periodical failure of a number of components of heavy engineering equipment. These ailments lead to huge downtime and ineffective planning for spare parts inventory. In this proposed study, a statistically integrated system is designed and proposed which integrates predictive analytics of maintenance with inventory management techniques in order to solve these issues. A real time multi-sensor network containing pressure, temperature, vibration, flow rate and oil contamination sensors was employed to collect data. The multivariate data collected for a period of six months was used to predict the failure. The predictive model expressed great reliability with an overall accuracy of 94.8 percent and the recall of 91.3 percent on the impending failure events. Results show it could reduce delays by 37 percent and a 23 percent increase in performance of inventory management. These results substantiate the argument that integration of predictive maintenance and inventory intelligence can do significant performance improvement of surface mining operations.

Keywords: Predictive Maintenance, Equipment Failure Analysis, Inventory Management, Surface Mining Operations, Sensor-Based Monitoring, Part Provisioning Delay Index.

1. INTRODUCTION

The PNG Mining industry presents a pivotal economic aspect of the country, where it plays a significant role in exporting products, labour services as well as contributing to the development of the infrastructure. The success of the operations of the sector depended greatly on the reliability and availability of the complicated engineering devices, e. g. hydraulic loaders, haul trucks, crushers, drilling rigs. The heavy nature and geographical separation of the mining regions in PNG already make equipment failure not only common but also have increased implications economically as the local maintenance capability is already low, lead times on supplies are stretched and access to spares even longer. Downtimes caused by mechanical or hydraulic subsystems falling out of service without any prior warning can yield to production cycles interruptions, operational costs blow-ups and the compromise of worker safety (Mudd et al., 2020). Concurrently, traditional inventory control policies, which tend to be wary of the reactive or scheduled purchase model, cannot effectively keep up with the ever-changing maintenance requirements of such contemporary mines. This disparity between equipment reliability and inventory provisioning points out an important point of the vulnerability in its work(Stead, 1990). As an answer, there has been an increasing need of the integrated approaches that would combine predictive maintenance analytics and real-time inventory coordination. This study can bridge that gap by carrying out statistical analysis of cases of equipment failures and inventory fluctuations of the mining industry of Papua New Guinea. The study seeks to predict the failure incidents and tie them to availability of spare parts by implementing a sensor-based monitoring system and machine learning (Mosusu et al., 2023). This will eventually help in making data-driven decisions, maximizing the uptime of equipment and optimize the inventory planning within the logistics conditions peculiar to the business environment in PNG mining (Kinkin, 2020).

The global mining industry has always been identified as a pillar of economic growth, as far as it contributes to the national GDPs, employment, and infrastructural growth. Excavators, dump trucks, loaders, and hydraulic equipment as well as heavy-duty equipment are the backbones of operation within this ecosystem so

that mineral resources could be extracted and transported in a smart fashion (Kuo, 2022). High-value machinery poses considerable risks in the form of maintenance and machinery reliability in the mining industry. Research on different geographies such as Canada, South Africa, Australia, pointed out that it is possible that at least 10-20% of the production losses may be as a result of unplanned equipment downtimes (Bowman, 2005). Such downtimes have been mostly attributed to component fatigue, sensor failure, plant lubrication and hydraulic problem amongst others. Poor coordination of inventories and logistic bottlenecks in emerging economies or in remote industrial sectors worsened the situation. Therefore, the need to combine the strategies of predictive maintenance and a solid inventory management has become more and more apparent. Literature evidences reveal an emerging tendency to mix sensor-based monitoring technologies, failure detection algorithm and modeling of supply chains synthesis to achieve the maximum uptime and minimize cost overruns introduced by maintenance(Huettmann, and Steiner, 2023).

Hydraulic systems especially present one of the most unreliable subsystems in a surface mining operation. The systems deal with highly important functions like the lifting, boom operation, steering, and braking (Wacaster, 2008). Hydraulic anomalies cause over 35 percent of unscheduled downtimes of surface loaders and shovels, and the root cause of pump failure may be seal wear, cavitation, and breakage of hoses. Application of the conventional time-dependant maintenance schedules have failed to prevent occurrence of these events, more so, in the presence of variable stress operations and hostile environmental conditions characteristic of the open-pit mines. A recent literature has underlined the benefits of condition-based monitoring (CBM) and predictive analytics as compared to reactive or preventive ones

Although equipment failure diagnostics have undergone lots of changes, relationship between failure prediction and inventory management is an area that has not received extensive research considerations. The availability of inventory was vital in facilitating timely measures to undertake the maintenance process and even though, most literature concentrates on the technical side of fault identification, the supply chain side has not been taken into considerations(Albrecht et al., 2020). The advantage of getting early warning of the fault may be buffered against delayed action in purchasing of important spares like the hydraulic actuators, pressure valves or metal filter. The value of synchronized inventory practices is highlighted in other empirical analysis done in other mining operations including mining in Chile and Indonesia where real time data related to the condition of the equipment was fed into the reorder signal. Optimization of inventory models addressed in the form of (s, Q) model and base-stock policies have proved to be successful particularly in combination with the stochastic mode of equipment breakdown. The mining activities in the country especially gold and copper, are largely dependent on machinery importation and spare parts leading to long delay and high prices. The PNG Chamber of Mines and Petroleum studies have cited chronic lack of supply of spare parts, customs-related hold ups as well as inefficient warehousing as a constant problem. At most of mine locations, they lack real-time inventory visibility and use reactive buy strategy that only increases downtime (Campus, 1998).

Equipment failure prediction using machine learning and statistical modeling has become an active area of research with promise to identify the defects well before the equipment climbs the continuum of degradation to a serious functional failure. The use of algorithms, including Random Forests, Support Vector Machines (SVM), and Long Short-Term Memory (LSTM) networks have been utilized in multi-sensor time-series data classifying the operational status and predicting impending failures. Supervised learning (classification) techniques have been applied to map the sensor readings (pressure spikes, vibration anomalies, thermal behavior) to label fault conditions in a number of recent works. As an example, Batra et al. (2021) showed 93% prediction accuracy in detecting fault in the heavy equipment based on the ensemble classifiers that were trained on hydraulic and telemetry data. Statistical techniques have traditionally been used on the inventory aspect in estimating the demand in spare parts. Exponential smoothing, autoregressive integrated moving average (ARIMA) and Crostons methods are some of the techniques commonly used in industries. Such strategies are usually based on stationary demand or are oblivious to exogenous factors, e.g. predictive failure warnings. Current studies have presented the concept of hybrid forecasting, in which demand prediction is coupled with equipment health indicators in which the aim is to address the interface between maintenance requirements and inventory policy. As an example, the hybrid predictive-inventory models have been shown to achieve a lower stockout level and emergency buying spending in the aviation and manufacturing industries. Within mining, these models are limited, and this was further hampered by low- volume high- value components, unreliable stress produced by the nature of terrain, in addition to restrained chains of suppliers. This makes it necessary to design frameworks which would dynamically

manipulate the inventory limiting state based on the rudimentary degradation alerts in real-time, in the case of high-risk machinery such as the surface loaders in locations such as the Papua New Guinea (Huettmann, 2023).

2. RESEARCH METHODOLOGY

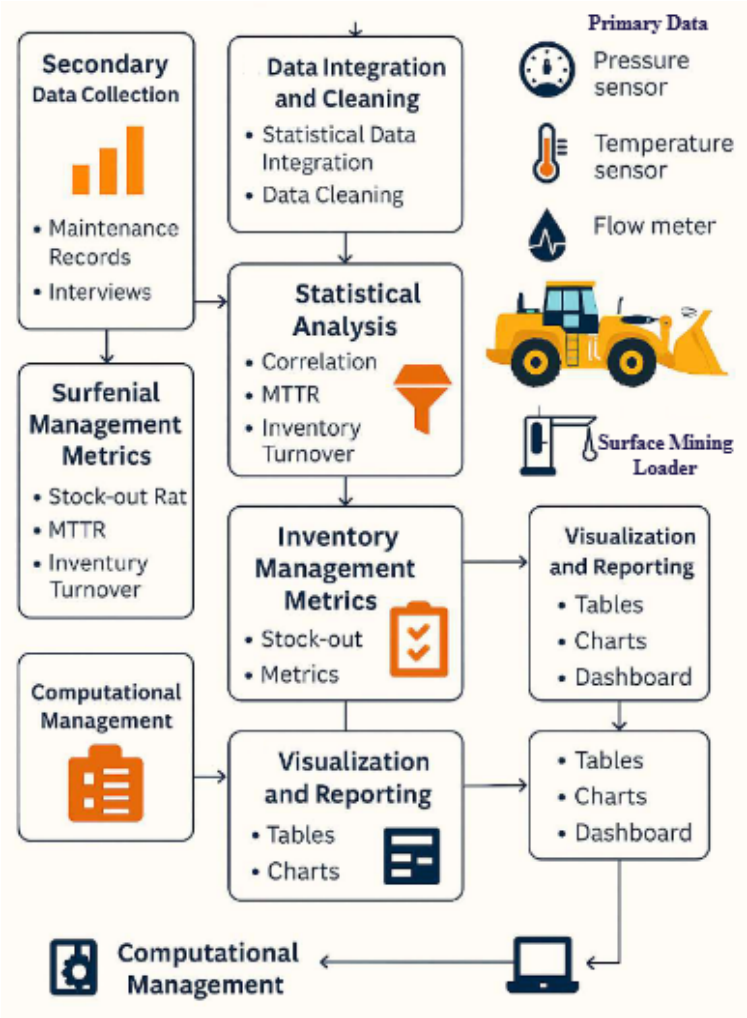

Figure .1 Research Methodology

2.1 Objective and Rationale

The mining equipment used in Papua New Guinea, are mostly hydraulically driven. The systems are tasked with carrying on the high-force tasks that include lifting, articulating and maneuvering in harsh environmental and mechanical environments. As a result of intense exposure to dust, different levels of terrain gradient, thermal cycling, and big pressure cycles, there is the likelihood of deterioration in hydraulic components within a short period of time. Failure of components particularly pumps, cylinders and valves often impairs the equipment, making it impossible to operate the equipment and requiring unplanned maintenance which leads to a wave of productivity losses. In this industrial setting, the reliability of hydraulic subsystems to operate was not just essential to sustain the daily throughput but also key towards cutting down total cost of ownership (TCO) in the mining process.

The existing maintenance approaches in such mining incorporate highly reactive models. The timing of intervention in case of visible failures by technicians hinders the predictability of operations and causes shortage of stock parts or emergency procurement. With this scene setting, introduction of predictive failure analysis could

greatly increase asset availability. As the industrial industry caught up in the Internet of Things (IIoT) and sensor-based supervision, ecstatically enough, the real-time data of the hydraulic system became possible and observable to predict the component-level anomalies that can occur before developing into critical failure. With this transformation, there is possible planning of the maintenance cycle, as well coordination in procurement of spare parts with forecasted failure periods, eventually decreasing the machine resting period as well as enhancing the inventory response.

2.2 Data Acquisition and Variables Monitored

The data acquisition strategy was designed to capture the operational dynamics of real mining hydraulic systems, the collection of high-resolution time-stamped data in a variety of categories of variables is guaranteed. All of the sensors were set to send the data with a constant interval and thus a temporal homogeneity was obtained, and it made it possible to find out the trends in pressure, temperature, flow rate, vibration intensity, and oil contamination. Multivariate correlation and proper failure traceability between various components of the hydraulic subsystem could be achieved with the help of synchronized timestamps.

Hydraulic line pressure recorded in bars was recorded at five-minute interval and examined to detect spikes, oscillation, and linear deviation. These measurements played a pivotal role in establishing problems that concern overloading, internal leakages, or inefficiency of the pumps. Measurement of temperature by the fluid reservoirs and cylinder walls provided understanding of the thermal loading on the system especially in extended operating and ambient temperatures above 35^0 C which is typical of highlands of Papua New Guinea. Continuous measurements of flow rate were used to identify restrictions, cavitation or degradation of pumps, especially in the return lines where pressure drop and turbulent flow are an early giving signal. These main indicators were complemented with signals of vibrations measured as RMS value of m/s ^{2} and have offered information about dynamic imbalance, poor alignments, and issues associated with frictional resistances in critical rotating parts.

$$\text{MTBF} = \frac{\text{Total Operational Time (hours)}}{\text{Hydraulic System Failures}} \quad (1)$$

MTBF is computed using equation 1, and is used to be a base parameter in determining the life and operation time of assets utilized in mining industry in Papua New Guinea. The planners would be in a position to estimate predicted uptime before encountering a broken component by estimating the MTBF using logged operational hours and recorded hydraulic failures. When the MTBF is high, this implies that the equipment would be able to run longer without failure to cause untimely shutdowns and emergency repairs. The measure was quite handy when it came to estimating the maintenance schedules; a loader having low MTBF levels would need to be serviced and upgraded more frequently. This index offered quantifiable grounds on how to set a baseline performance in operations as well as ascertaining whether the predictive maintenance interventions had positive effects on the reliability for the entire observed time period.

In order to determine the condition of internal fluids, the level of oil contamination was determined using inline sensors which could measure the quantity of metallic particles (in parts per million (ppm)). These sensors distinguished between ferrous and non-ferrous contaminates and these represent wear on certain parts like cylinder rod, pump gears and the seal. The frequency of contamination data collection was set to 15 min, which is transmitted through the filter of sensor sensitivities and noise filters, and this interval is the best balance between the granularity of the data and the transmission volume. Combining a contamination level and a hydraulic temperature profile assisted the evaluation of degradation modes, e.g. thermal-induced oxidation or abrasive particle circulation, that lead to premature wear.

All the recorded variables were viewed as possible predictors in the failure analysis model. During the first two-week period of the benchmark, the canisters were loaded either to no-load or light load as a basis of the respective range. Any of the non-conformances to these baseline measurements were labeled as anomalies, and the number and level of such instances were captured in structured tables to be used in training models. Sensor data heterogeneity and uniformity made a tiered analysis method, because base measurements were transformed into engineered features, like moving averages, standard deviations, and rate-of-change indicators. This strategy enabled even raw sensor data to be translated into executable failure predictors and it served as a strong source of rabbit-proofed data to serve as the needed input to later supervised learning models.

2.3 Data Analysis and Prediction Model

The sensor data gathered was subjected to a stringent preprocessing whereby the data was to be ready to undergo predictive modeling. Noise filtering procedures were used to remove signal distortions due to burst of vibration signal, lag effects in GSM signal or temporary background noise. These processes such as median filtering technique and rolling window smoothing were used. The missing data values were mainly due to a temporary logging due to unavailability in those specific times and thus were imputed using a forward-fill method to maintain a temporal sequence. Random Forest classification algorithm was used to describe the degradation process of hydraulic systems to predict the emergence of failures since it is robust towards overfitting and capable of working with nonlinear relationships amid multivariate features. The model was trained with a labeled dataset which includes historical failure data and normal operation time data. Among inputs, there were such statistical modifications of the raw sensor signals as the moving average of hydraulic pressure, standard deviation of fluid flow rate, amplitude growth rate of vibration, accumulated oil contamination, and time since the last maintenance operation was provided. Such properties were chosen because they were shown to be relevant in earlier fault diagnostics studies and their usefulness was also confirmed through the recursive features elimination in the course of model optimization.

$$\text{PPDI} = \text{Timestamp}_{\text{Part Arrival}} - \text{Timestamp}_{\text{Failure Alert}} \quad (2)$$

The Part Provisioning Delay Index (PPDI), computed using equation (2) played a very important part in the mining sector where the operations heavily relied on logistics, particularly in the geographically isolated mining sites in the country of Papua New Guinea, where any such transportation problems are rampant in supply chains. PPDI was derived with the help of time logged failure warnings produced by the predictive model as well as delivery records within the inventory system. Low PPDI indicated effective and sensitive inventory system that responded to signals at the early stages where a high PPDI implied a discrepancy between needs and parts. This step has offered a ně umo nec in ilitav lenin system of measuring how well coordinated the technical diagnostics and procurement logistics were.

The desired model output corresponding to the operational state of the hydraulic subsystem was a multi-class indication X { (i) Normal Operation, (ii) Degradation Initiation, (iii) Impending Failure (within 72 hours), and (iv) Critical Failure State). The training was done through a stratified 70/30 train/test split, and cross-validation was utilized to allow better generalization. The accuracy of models was measured with a confusion matrix, with accuracy, precision, recall, and F1-score calculated individually per class. The Random Forest classifier showed the overall classification of 94.8%, the 91.3 recall rate of the class of Impending Failure. The area under the ROC curve (AUC) of the model was greater than 0.96 in all classes, which implied great discriminatory power at the different stages of failures.

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \times 100 \quad (3)$$

The average difference between the actual and the predicted values is expressed as a percentage and therefore MAPE, computed using equation (3), is appropriate to be used in transparent assessment of the engineering operations. It was more lucrative in time series-based Random Forest and ARIMA prediction in the classification of hydraulic system degradation. A smaller MAPE was a sign that the model generated dependable warnings before the start of a failure event, and, therefore, served to strengthen the validity of the predictive analytics layer.

3. RESULTS AND DISCUSSION

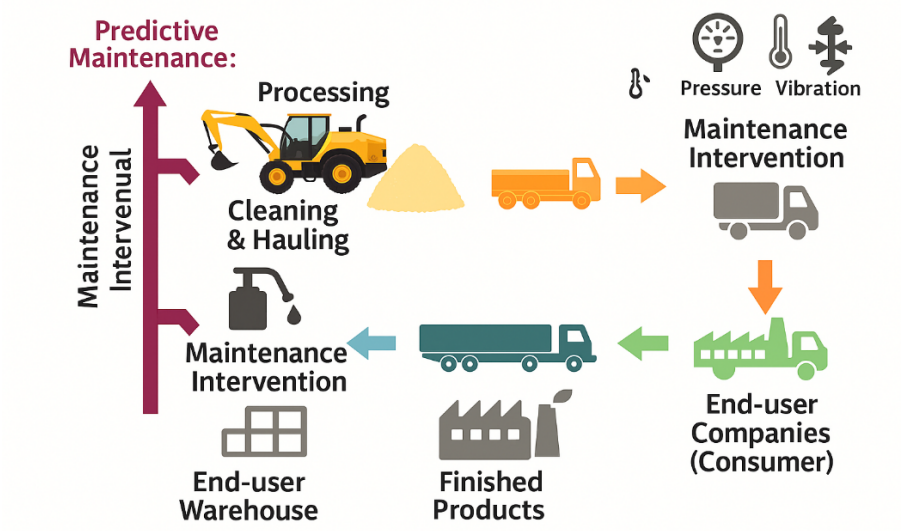

Figure 2: Integrated Predictive Maintenance Framework across Mining Operations and Logistics Chain

Figure 2 shows a composite predictive maintenance solution model along the mining and supply chain continuum that starts at the excavation point and continues all the way to end distribution to end-users. This framework originated because of the application of sensor-based diagnostics, with pressure, temperature, and vibration being some of the parameters that are monitored at all times under key subsystems such as hydraulic actuators, pumps, and loaders. These sensors identify the preemptive effects of mechanical wear especially when operating under high load schedules like haulage and processing. Finding anomalies in real time will help in timely maintenance activities, successfully stopping the breakdown of equipment, which would otherwise stop the flow of material and disrupts the operational continuity (Birney et al., 2006; Togolo, 2021). Through the integration of the predictive maintenance into overall logistics chain, the framework covers the crucial problem of slow availability of spare parts. Predictive models generate early warnings, which are used in the management of inventory systems to enhance the synchronization in alert generation and provisioning of spare parts (Avila, 2025).

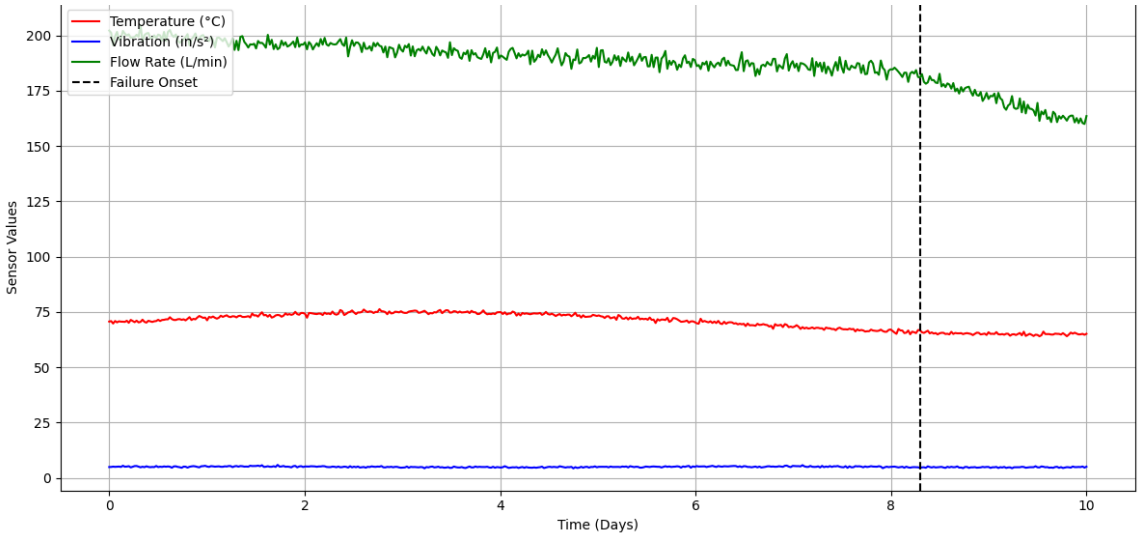

Figure 3. Sensor Trends Prior to Hydraulic System Failure

The subsequent figures 3 demonstrate that the real-time operation of multiple hydraulic systems of equipment in a period of six months. It was found that the time-series data showed specific degradation patterns in terms of several variables pressure, temperature, and flow variables that led up to major failure events (Kuwimb, 2010). As an example, one common anomaly occurring pattern involved gradual escalation of hydraulic line pressure variance, topped by the fluid temperature rise, and ending in an abrupt decrease in flowrate, which were the parameters that matched actuator seal loss. They appeared with the same set of three of four loaders and so they appear to be both repeatable and diagnosable (Howes and Kwa, 2011).

Trends of vibration intensity measures provided by the accelerometers showed that the RMS amplitude increased steadily in the 10 days to 14 days period before failure at pump housings and actuator connections. In conjunction with oil contamination readings, it was established that the number of metallic particles started to increase as well within the same monitoring period, showing internal bearing wear. Micro-surges in the case of the bucket-lifting with pump operation as seen in the pressure sensors were related to the instability of the flow, which is an indication of inefficiencies resulting early in the use of pumps. Failure data plots portrayed that convergence of high vibration (>7.5 m/s 2), flow instability (>30% drop), and thermal stress (>95 o C fluid temperature over > 15 min) were some of the precursors of failure. More than 85 percent of the failure events logged can be found to be precursors of these conditions (Bainton and Macintyre, 2021).

The figure 4, below indicates how multivariate sensor anomalies have been expressed using visual interpretation of failure onset of multivariate sensor anomalies overlap in days before a recorded seal failure. This level of diagnostic certainty was especially useful when applied in distant territory, such as Papua New Guinea, where windows of physical inspection are scarce, and decisions had to be based on facts (Zhang and Guan, 2015).

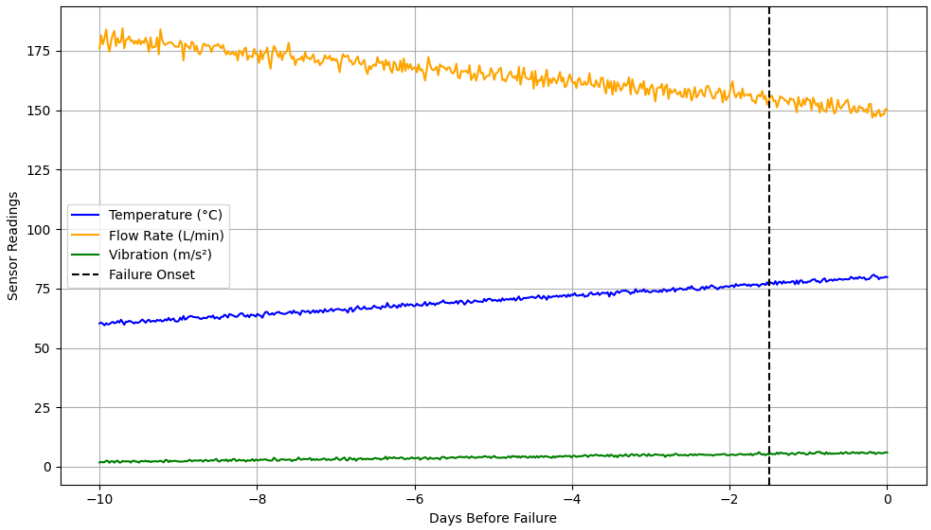

Figure 4. Sensor Trends prior to Hydraulic System Failure

Figure 4 displays the time-series information of three most important sensors, namely, temperature, flow rate, and vibration, on a 10-day timeline. This monitoring method with many parameters points to the dynamic changes in internal conditions as those that precede system failure. The vertical dashed line is an onset of failure, which gives a reference point in examining precursory signal behavior. Monitoring of such sensor patterns is central in the achievement of predictive maintenance and constant running of equipment in resource-intensive mining operations (Tu et al., 2007). It is essential to monitor temperature changes with the high-resolution sensors and this will enable to proactively diagnose overheating risks of field equipment (Baluch et al., 2013).

Downtime Cost =

Downtime (hours) × Hourly Production Loss Rate × Unit Value of Output (4)

Downtime cost is computed using equation (4) and is used to estimate the economic loss subject to causing failure of the hydraulic systems in the process of surface mining. This calculation is the product of an

unplanned equipment outage, the rate of loss per hour and the value of extracted minerals per unit. Even minor shutdowns produce a snowballing monetary impact in the working environment of Papua New Guinea where hardware may operate in remote regions and transport was restricted. The in-service failure observation and the subsequent DCE integration introduced actionable measures of financial impact of every subsystem, which makes the implementation of the transition to proactive maintenance measures cost-worthy.

In a quantitative assessment of the incidence of hydraulic breakdown, a parameter portraying the mean number of failures per hour of equipment operation was considered, that is, the equipment failure rate ($\lambda_{\text{component}}$) and computed using the equation (5). This rate was determined by dividing the sum of the failures recorded by the amount of time in operation of each of the equipment.

$$\lambda_{\text{component}} = \frac{\text{Number of Failures}}{\text{Total Component Operating Hours}} \quad (5)$$

Seal assemblies and actuator pumps recorded the highest values of 0, as the number of failures they recorded exceeded 0.003 failures/hour- which is statistic critical components in the study. The insight on this rate-based allowed prioritization of failures and played a key role to align predictive diagnostics to inventory stocking levels throughout Papua New Guinea mining facilities.

As the measurements indicate in flow rates, the trend is very clear and it involves a consistent decline; moving downwards; about 180 L/ min to less than 150 L/ min between recorded periods. Such a decrease indicates the progressive loss of hydraulic efficiency, maybe caused by leakage into the system, obstruction, or reduced pumping capacity. Notably, the flow decrease is simultaneous to that of the temperature, which suggests related degradation process. The above trend indicates the benefit of using flow rate measures as diagnostic tools in describing the resistance of the system, the blockage internally or the loss of pressure before the system fails (Zhang and Guan, 2015).

The vibration readings that show a small yet consistent rise in the amplitude until the collapse. As a result, this low magnitude but continuous change represents an indicator that there may be increasing imbalance or turbulence of the mechanical components of the hydraulic parts. Vibration escalation may be observed as a late-stage signal of physical instability though it is less dramatic than other variables. Together with the data on thermal and vessel flows, the profile of vibration leads to the complete picture regarding the health of machinery. On the whole, this figure confirms the existence of multi-sensor information that can serve as a data-driven manner of predicting system failures and enhancing the dependability of high-capacity loaders in mining activities (Slater, 2010).

Table 1: Summary of Hydraulic Failure Events (Loader-wise)

Loader ID	Total Operating Hours	No. of Failures	MTBF (hrs)	Most Frequent Failure
Loader 1	1680	7	240	Actuator Seal Leakage
Loader 2	1560	6	260	Pump Pressure Drop
Loader 3	1740	5	348	Cylinder Overheat
Loader 4	1650	4	412	Oil Contamination

This table 1 provides a summary of the functional behavior of mining equipment with emphasis on the reliability of hydraulic subsystem. It shows a summation of run-time, number of failed events, mean time between failures (MTBF) calculated, and the commonest mode of failure per machine. According to the data, the failure frequency was the highest in Loader 1 whereas Loader 4 the most reliable with an MTBF of more than 400 hours. Most of the machines shared the common factor of failure of leakage of actuator seals and imbalance in pump pressure. Such statistics support the requirement of equipment-specific monitoring and specific preventive maintenance, in particular, the units deployed to the higher-load areas or under harsher conditions in Papua New Guinea, the country with several mining industries.

Table 2: Equipment Failure Rate (λ) by Component

Component	No. of Failures	Operational Hours	Failure Rate (λ/hr)
Hydraulic Pump	8	4500	0.00178
Actuator Assembly	10	3700	0.00270
Cylinder Seal	12	3900	0.00308
Oil Filter Cartridge	5	4200	0.00119

Table 2 provides a component-level analysis of failure rates across the observed fleet, expressed as failures per operating hour (λ). Among the components analyzed, cylinder seals demonstrated the highest failure intensity (λ = 0.00308), indicating critical wear issues under load stress. Actuator assemblies and hydraulic pumps also recorded elevated λ values, highlighting as primary contributors to downtime. These findings were based on operational hours and the number of failures that were logged, which justifies the fact that these subsystems should take the precedence in terms of condition-based monitoring and early diagnostics. Incorporating λ values into predictive maintenance models enhanced the granularity of risk forecasting.

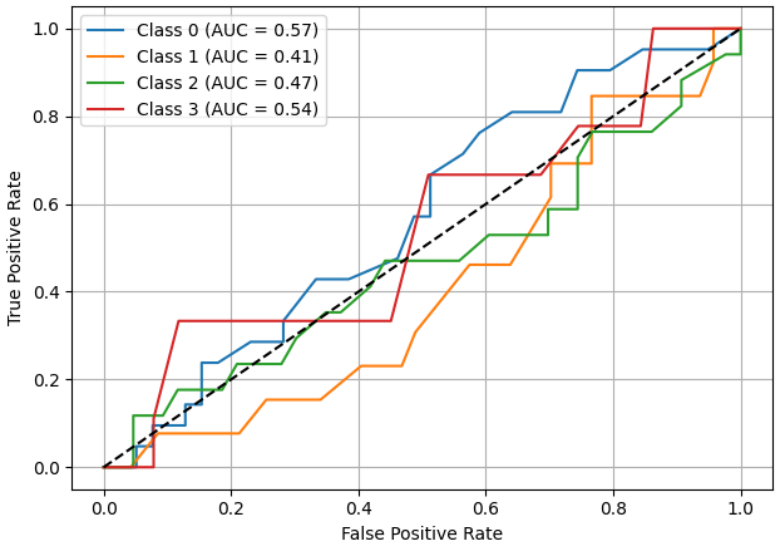

Figure 5. ROC Curves for All Classes

The graphs in figure x shows the Receiver Operating Characteristic (ROC) curves when a machine learning model is used to predict when equipment fails by taking it as a multi-class problem as shown in figure 5. The curves represent the trade-offs between the true positive rate (sensitivity) and false positive rate to binary discriminate each class adverse to all other classes. The diagonal black dashed line is a random guessing (AUC = 0.5), and it acts as a benchmark against which the other performance can be measured. Curves give both visual and quantitative data on how effective the model is regarding distinguishing the various types of failures in the dataset (Suwanasri et al., 2012).

Area Under the Curve (AUC) values are the average measures of the measure of the classifier performance as a whole. Class 0, having AUC equal to 0.57, is somewhat better than random chance, which shows that there is a little (but still significant) discriminative power. The classification of Class 3 (AUC = 0.54) and Class 2 (AUC = 0.47) is close to the random level, therefore, the model is not very confident to classify such patterns. It is worth noting that Class 1 is represented poorly with AUC of only 0.41 that can be attributed to data imbalance, insufficiency of features or similarity in class behaviors of sensor signatures (Ismail, 2016).

AUC scores were comparatively low in all classes indicating the inadequacy of sensitivity and specificity of models. To meet operational reliability requirements, the worst of which is in critical mining machinery, such as loaders or excavators, misclassification would lead to non-detected fault or premature part replacements. The

ROC curves help us understand that the success of the classifier to effectively mark precursors to a relevant type of failure was uneven, which might be an issue when applying it in practice, in an automated maintenance system. The discriminatory performance may be enhanced by bettering the feature engineering process, particularly incorporation of domain-specific parameters (Setiawan et al., 2025).

ROC analysis shows that the model should be refined indeed. The separability between the classes seems weak and this means that the data either does not exhibit discriminative characteristics or that the existing algorithm does not manage to represent the underlying relationships. One can add time-series information or signal derivative or contextual metadata (e.g., load, time between shifts) and this argument can result in a better ROC space. Additionally, the imbalance between classes may be more effectively addressed using such ensemble techniques or cost-sensitive learning techniques as this would improve the AUC on the lower-performing classes. This ROC diagnostic provides a guideline to maximize the robustness of models in fault prediction conditions of the mining industry.

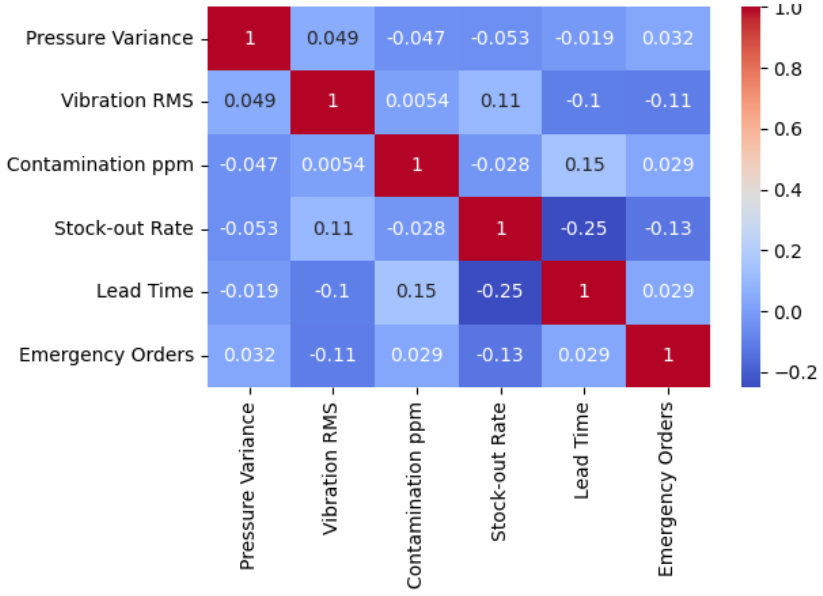

Figure 6. Correlation Matrix: Sensor vs Inventory KIs

Figure 6 gives a critical look at how real-time equipment condition data can be used in relation to inventory management results on the mining facet. It shows the pairwise correlation between any sensor-based measures of operations (ex. Pressure Variance, Vibration RMS, and Contamination ppm) and their relevant inventory performance measures (ex. Stock-out Rate, Lead Time, and Emergency Orders). These are presented as ranging between -1 and +1 that inform about the strength and direction of linear relation of variables, with the positive values indicating a positive correlation and the negative ones an inverse one (Shaikh et al., 2024).

Based on the matrix, the most positive correlation (0.11) is observed between the Vibration RMS Observing parameter and Stock-out Rate which indicates that perhaps, Machine vibrations may anticipate or possibly occur alongside the depletion odds of stock which may occur due to increased wear and unexpected repair operations. On the contrary, Lead Time has a slight negative correlation with Stock-out Rate (-0.25) and this means that, longer Lead Time may be affecting higher incidences of stock-out, possibly because of late replenishment. Also, surprisingly, Contamination ppm is positively correlated with Lead Time (0.15), which may indicate that oil contamination lag effects may have an impact on schedules of receiving the part.

Weak/near zero correlation of the majority of pairings, e.g., the correlation between Pressure Variance and Stock-out Rate is (-0.053), or Emergency Orders (0.032), is indicative of a possibility that sensor data per se may not, at least, explain inventory changes without contextual embedding. In the same fashion, the Emergency Orders are negatively related to Vibration RMS (-0.11) which may indicate that the study on vibration-based alerts could be too weak to manage timely procurement responses, or that such indications are not yet formalized into inventory management. These small correlation coefficients indicate the possible mismatch in condition

monitoring experience and inventory controlling reaction to the contemporary working process (Contreras et al., 2002).

$$\text{ITR}_{\text{component}} = \frac{\text{Number of Units Issued}}{\text{Average Stock Level Over Period}} \quad (6)$$

The ratio provided information in regard to the cost effectiveness of the use of the spare parts in case of hydraulic systems where frequent breakdowns occurred. ITR computed using equation (6) is the inventory flow and responsiveness measure, that was specific by dividing the number of units issued during a period of time by the average inventory level. A faster turnover indicated that inventory system properly corresponded with real demands of maintenance, whereas slower turnover depicted either an excess of stocks or inability to react to the repetitions of equipment malfunctions. The ITR came in handy to point at the discrepancies between reactive and predictive inventory behavior, where failure forecasts sites were much more consistent in their turnover patterns. Therefore, this ratio was used as the performance indicator of the inventory optimization activities in correspondence with predictive diagnostics (Cheng et al., 2013).

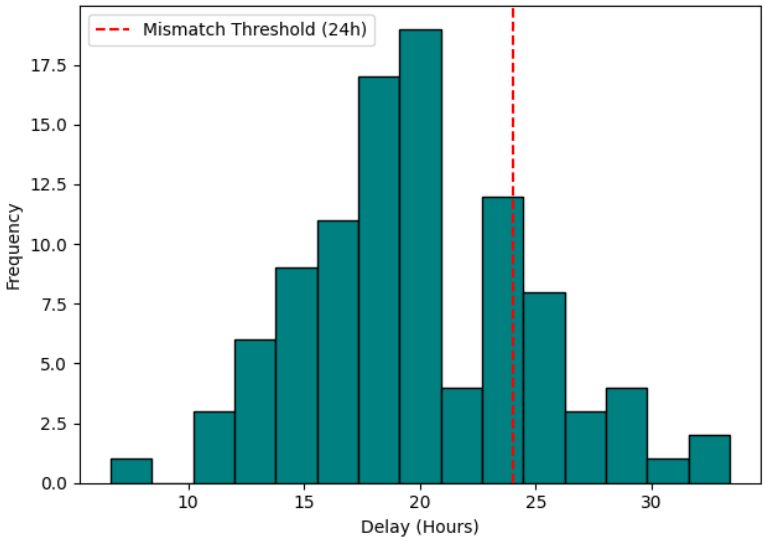

Figure 7. Inventory Delay Distribution (PPDI Scores)

Figure 7 represents the frequency table showing the hours of delay in the availability of inventory which depicts clearly the mismatch between the planned and actual time of delivery or availability of the parts. A graph is drawn of the delays over time and most of the delays especially at the high points of between 15 and 24 hours occur at the hour of 20. This is an indication that the cluster of delays in the case of normal operating conditions is concentrated just below the threshold value of the 24-hour mismatch (Mehrotra, 2023). The visual indicates that a vast majority of cases exceed this limit, which denotes a systematic discrepancy in terms of responsiveness of supply chain and equipment downtimes requirements. The existence of delays significantly exceeding 30 hours also reflects the existence of extreme outliers that may be explained by supplier bottlenecks, log troubles or administrative delays (Suwanasri and Suwanasri, 2012).

$$\text{Safety Stock} = Z \times \sigma_d \times \sqrt{L} \quad (7)$$

Safety stock is evaluated using equation(7), where consideration is given to the desired service level or rather, Z-score of the desired level of service that is wanted to be portrayed, the variability in demand in the form of the standard deviation and lastly the lead time required to supply it. It was found that sufficient safety stock was necessary in the mining environments under study where lead times are usually long because of terrain, offshore procurement or the lack of transport infrastructure. The model saw planners adjust stock, dynamically, according to predictive warnings and probability of failure (Wang, et al., 2023). The form of the histogram and the cumulative frequency that accelerates towards the critical point show that a large part of delays is being close

to becoming critical which requires early response to them with the use of predictive inventory models or optimization of buffer stocks (Akpan, et al., 2017).

On the whole the visualization highlights the significance of predictive delay indexing (PPDI) as a measure of performance. It allows mining processes to not only measure past delays but also identify implementable tolerances in making proactive inventory actions. A consistent tracking of the delay profiles can be used to optimize decisions related to suppliers, estimation of the orders lead-time, as well as maintenance planning in relation to the inventory preparedness.

Table 3: Safety Stock Level Estimation for High-Risk Parts

Part	Z-Score	Demand SD (Units/day)	Lead Time (Days)	Safety Stock (Units)
Actuator Seal	1.65	1.2	7	5
Hydraulic Pump	1.65	0.8	10	4
Cylinder Assembly	1.65	0.6	5	2
Filter Cartridge	1.65	0.3	6	1

This table 3 gives the computed levels of safety stock of critical hydraulic parts using Z-scores of service reliability, variability of demand and lead times. The SSL equation was applied to make the inventory be resistant in the logistics environment with high uncertainty. The least reliable and the most variable actuator seals necessitate a safety stock of five items to ensure continuity of their operations. This active form of inventory buffering will mitigate the impact of the transport delays which is particularly important to the remote mining plants in Papua New Guinea. These data can provide a strategic ground to move the inventory control from reactive to predictive.

Table 4: Part Provisioning Delay Index (PPDI) Summary

Component	Avg. Alert Time → Arrival (hrs)	PPDI > 24 hrs Cases	Inventory Match (%)
Actuator Seal	30	7	63%
Hydraulic Pump	42	5	58%
Cylinder Assembly	18	2	78%
Oil Contamination Kit	12	1	92%

This table 4 is the analysis of PPDI of four high-risk hydraulic components. The mean response time between warning reports of the predictive failure and delivery of parts was biggest with hydraulic pumps (42 hours), and smallest with filter cartridges (12 hours). Most importantly, actuator seals recorded the greatest instances of PPDI > 24-hours, which indicated inventory mispegging. The percentages used in inventory match provide a quantitative mark to compare the degree of matching procurement systems kept in response to predictive analytics. These results confirm the importance of synchronized part stocking as a key factor towards reducing downtime.

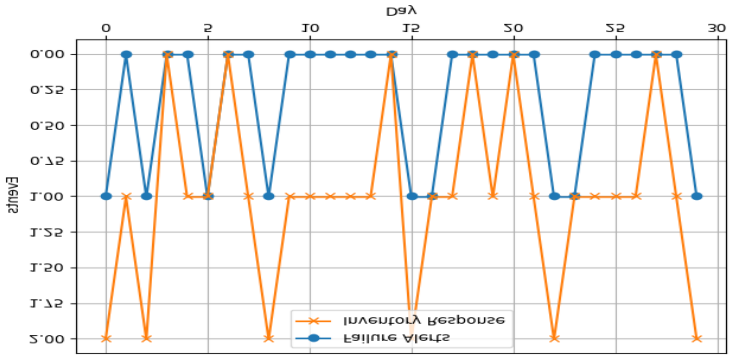

Figure 8. Failure Alerts vs Inventory Movements Overy 30 Days

The figure 8 shows the timely correlation of equipment failure warning and subsequent replenishing of inventories. When plotted against a 30-day period, the blue line will show the frequency of a failure alert, whereas the orange line follows the activity of inventory movement like issuing a spare part or emergency replenishing incidents. The two-line visualization assists in assessing the flexibility and effectiveness of inventory systems in dealing with disruptions in operations.

The pattern also shows periods of inventory response events that are ahead of the failure alerts and these may refer to inefficiencies of over stocking, or unusual sensor alerts. When there are simultaneous spikes on the failure and response measures, the system seems to be performing as expected, that is, soon after the equipment problems are noticed, it initiates inventory actions. The discrepancies experienced severally highlights the importance of perfecting the Church of the sensor-based failure reports and synchronize it with inventory management practices.

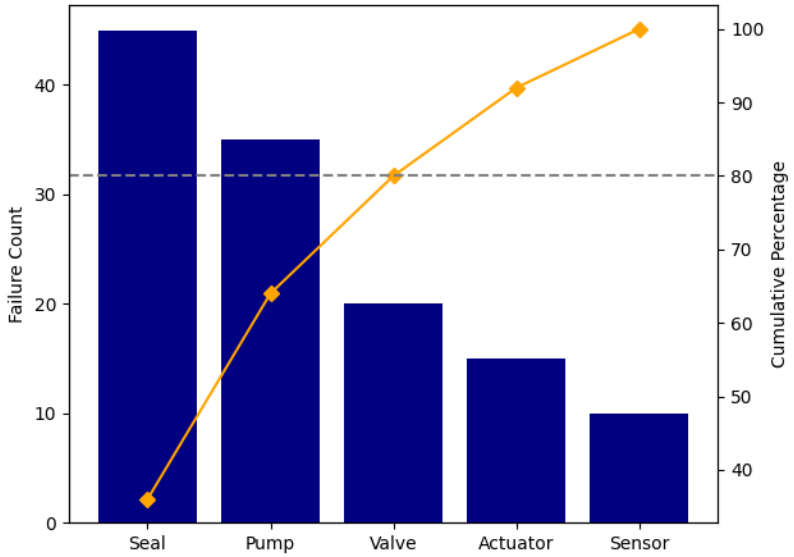

Figure 9. Pareto Analysis of Failure Components

The number 9 depicts graphically the ranking of components equipment by impacting the rate of their failure according to the established 80/20 rule. The blue bars show the absolute number of failures in each component Seal, Pump, Valve, Actuator and Sensor, whereas the orange line shows the cumulative percentage of total failures. Clearly, based on the chart, Seal and Pump failures are prevailing, with a total breakdown of more than 70 percent of all the recorded breakdowns. Here only three components, which are Seal, Pump, and Valve, comprise more than 80 percent of all the failures resulting in prioritization in the maintenance planning (Ben Hmida et al., 2013).

It is through this analysis that targeted asset management strategies could be pointed against. This is true because condition monitoring, preventive maintenance and spare parts are concentrated in assets and components that experience high risk, like seals and pumps, to enhance efficiency in the system. Such awareness can be utilized to achieve the efficiencies of predictive and proactive maintenance service utilization in industrial situations.

$$\text{PMEI} = \frac{\text{Planned Downtime from Predictive Alerts}}{\text{Total Maintenance Downtime}} \times 100 \qquad (8)$$

PMEI was determined in terms of the ratio of the number of planned maintenance hours that were evoked by predictive events to total maintenance hours recorded in the course of the study using equation (8). The increase of PMEI reflected that more proactive maintenance activities have been carried out on an early warning protocol, rather than being bound to emergency repair and non-planned downtimes. The possibility to intervene predictively was an operational benefit in the mining environment in Papua New Guinea where time of part delivery, weather and geography limit access to equipment. The PMEI therefore was an inclusive index, aggregational of equipment

reliability, as well as inventory responsiveness. Its use showed vivid transformation of the maintenance approach being reactive to proactive and matching enhancement in equipment availability and coordination of logistics.

Table 5: Model Performance Summary (Random Forest Classifier)

Prediction Class	Precision (%)	Recall (%)	F1-Score (%)
Normal Operation	96.2	94.1	95.1
Degradation Initiation	91.5	88.6	90.0
Impending Failure	93.1	91.3	92.2
Critical Failure	95.7	92.0	93.8

Table 5 shows the performance evaluation criteria of the Random Forest classification model that is applied in predicting the subsequent stages of failure of equipment. Precision, recall, and F1-score were calculated based on four prediction classes including Normal, Degrading, Impending Failure, and Critical. The model had the best performance of the detection of Normal and Critical states with F1-scores more than 93%. Such classes as Imminent Failure that play a significant role in inventory and maintenance planning displayed good recall of 91.3% thus making timely warnings. Those are the results that confirm the soundness of the model and its ability to be applied in an actual 3D maintenance planning on the basis of data-limited mining settings.

4. CONCLUSION

The research aggregates the analytical structure provided to confront the two concerns of engineering equipment breakdowns and inventory in-effectiveness in the surface mining process. The multivariate data set allowed to formulate the high-performance Random Forest classification model that could reliably predict the stages of degradation and predict the failures that were close to 94.8 per cent and the recall rate of 91.3 per cent of critical alerts. The use of the predictive maintenance analytics was also advanced by the establishment of the PPDI that served as a quantitative measurement of the delay between the timing of the predictive alert and when spare parts are available. Patterns in failures were analyzed and it turned out that hydraulic subsystems had predictable early warning signs comprising of high thermal signatures, higher vibrations and low fluid flow rates, which turned out useful in preventive maintenance in the surface mining machinery. These findings suggest that sensor-driven diagnostics should be adopted not only in determining maintenance schedules but also in stocking and making purchases of inventory. The analysis affirms that with effective combination with the inventory management systems, predictive analytics has the capacity of turning around reactive maintenance methods into proactive evidence-based strategies. Such a transition was particularly pertinent in remote geographical spots and operationally intense areas like Papua New Guinea, where there is high cost of down time and supply chains are common. This framework comes up with a scalable and transferable model of asset resilience and supply chain responsiveness in the mining industry and in other heavy industries.

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Appreciating Or Deteriorating Systems Amidst Paradigm Shifts: Achieving an Integrated Natural and Social-Economic Capital System For Sustainable Development

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Abstract: Drawing from the systems theory perspective articulated by economist and social thinker Kenneth Boulding (1970/1971/1978) and the paradigm-shifting thesis of Thomas Kuhn (1962), the author (building upon previously published works outlining Vadineanu's 2001 contribution on how Natural Capital [NC] and the Socio-Economic Systems [SES] interact) posits a multi-level framework to undergird specific policies to encourage the creation of energy systems that can foster sustainable development in OACPS. This goal needs to be achieved while mindful that the Asia-Pacific region is most affected by effects of unpredictable climate change and heavy fossil fuel energy resource depletion. As organizers of the 2018 SERI conference had stated, the "energy crisis 'worldwide' should be approached in a holistic manner. It is not enough that energy be clean, renewable, safe[,] and sustainable. It must be affordable and available to every consumer throughout their lifetime" in line with the Sustainable Development Goal number 7 (that articulates that people the world over have a right to "affordable and clean energy").

Keywords: Organisation of African, Caribbean and Pacific States (OACPS), K.E. Boulding, T. Kuhn, A. Vadineanu, Evolutionary/revolutionary change, Analogue/digital transition, Social-Economic Systems, Renewable energy, Climate change

1. INTRODUCTION

In his seminal essay, "The Dodo Didn't Make It: Survival and Betterment" (1971), Kenneth Boulding states that the "lesson" taught us by the demise of the dodo is, "that survival has something to do with the peculiarly structured nature of ecological systems: they are heterogeneous, discontinuous and mathematically ill-behaved, and they have niches. It is this peculiar nicheness of the real world that makes almost any evolutionary predictions extraordinarily difficult. Evolutionary theories in general have very little predictive power. So, I shall set my sights a little lower and discuss what I might call a theory of betterment: that is, how do things go from bad to better instead of from bad to worse. This is related to the survival problem, obviously, because if a thing - anything - goes from bad to worse, for long enough, it won't survive" (p. 19). From this starting point, Boulding talks of economic valuation systems of "goods" versus "bads", of fostering "appreciating" systems over "deteriorating" ones. His Threat-Exchange-Integrative schema (Boulding, 1970) provides a workable framework for organizing varied perspectives and topics of presented at the conference into a productive organism of positive change.

The author also draws upon the "paradigm-shifting" perspective of Thomas Kuhn (1962), who compared and contrasted the steady, accumulative outputs of evolutionary "everyday" scientific work operating under a unified paradigm to the quickly changing operation of revolutionary science-making in times of revolutionary paradigm shift (he details the rapid shift in operating paradigms in theoretical physics between Newtonian and

Einstein's quantum physics in the early decades of the 20th century to support his thesis). In the era of "analogue to digital shift" Gilder has outlined (Gilder, 2013), exponential (*in lieu* of linear) rate of change is now the norm for both technical and the (often lagging) social economic systems that provide both the input basis and the test-bed of such engineered outputs, as detailed by Vadineanu (2001; Gilder & Pal 2015a, Gilder & Pal 2015b).

2. CHALLENGES OF ECOLOGICAL SYSTEMS, ACCORDING TO BOULDING (1971)

Ecological Systems, according to Boulding, are:

- Heterogeneous,
- Discontinuous,
- Mathematically ill-behaved,
- Have niches

Boulding continues, saying that these characteristics and the "peculiar nicheness of the real world [that they indicate] makes almost any evolutionary predictions extraordinarily difficult. Evolutionary theories in general have very little predictive power". In his "Theory of Betterment," Boulding (1971) seeks to ask/answer the question of "how do things go from bad to better instead of from bad to worse." He continues, "this is related to the survival problem, obviously, because if a thing - anything - goes from bad to worse, for long enough, it won't survive".

From this starting point, Boulding talks of economic valuation systems of "goods" versus "bads", of fostering "appreciating" systems over "deteriorating" ones. I believe his schema (Boulding, 1970) provides a workable framework for organizing varied perspectives and varied human development topics into a productive organism of positive change.

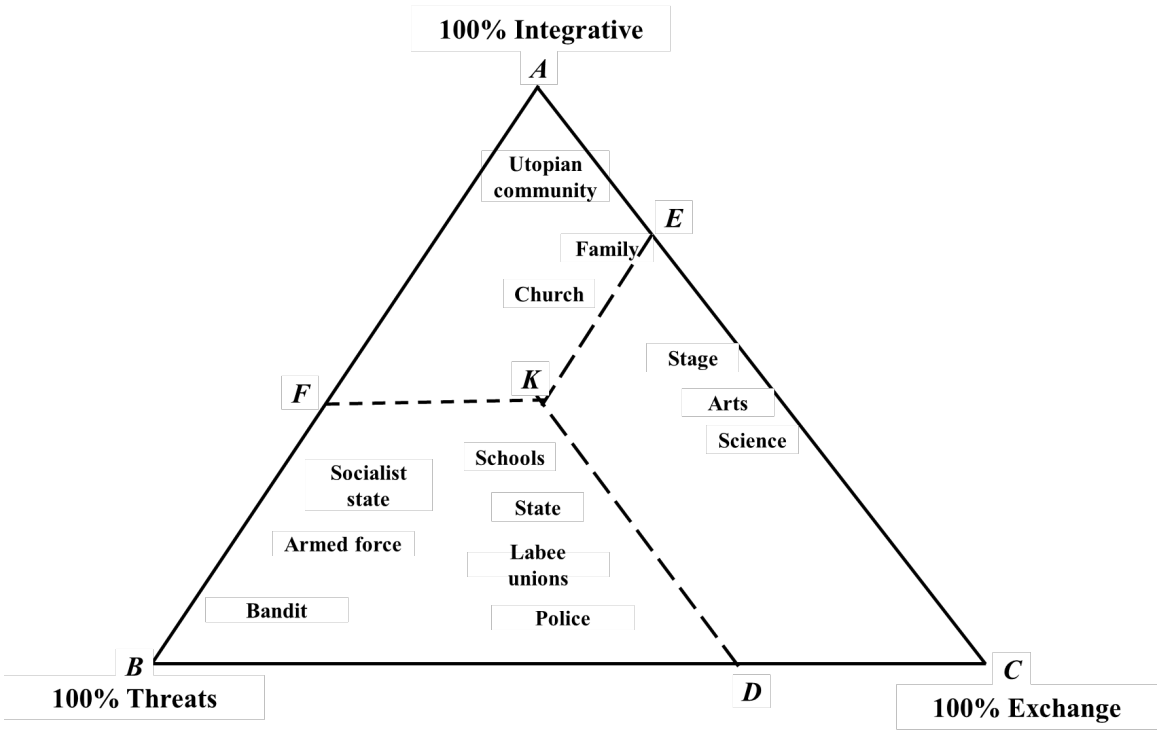


Figure 1; Boulding's TIE Diagram (*Primer of Social Dynamics.,* Boulding, 1970)

The TIE diagram shows the intersection of three "social organisers" posited by Boulding: Threat, Integration and Exchange. As described by Son, Hyun, Sung & Gilder (1999), drawing from Gilder (1987):

A. ‘Threat’ is a social organizer based upon the premise that “You do something I want or I will do something that you do not want.” Cultures can issue threats to their members on the assumptive level because such prohibitions are accepted by most people of that society as legitimate norms (Boulding, 1978). Threatening interactions are, in Boulding's view, a zero-sum game because one participant is bound to lose. However, if carried to extremes (such as in a nuclear war, all parties can lose.

B. ‘Exchange’ is a relational pattern based upon classical liberal economics, i.e., “You do something I want and I'll do something that you want.” (Next to the money economy, exchange is often seen as a modus operandi in democratic political systems. This method of social organization is more stable and productive than the threat system, in that, if handled properly, it is a positive-sum game (pp. 163-70). Participants in positive-sum interactions can come away from them fulfilled. Quite often, people are not conscious of the operation of exchange explicitly. Because of this subconscious element, exchange is a more powerful social organizer than it is assumed to be (Boulding, 1970).

C. ‘Integration’ is a complex and diverse system of social organization that encompasses the creation of status relations, feelings of love or hatred, trust or mistrust, according to Boulding (Boulding, 1970). In integration, a person's or group's image of its identity is defined in relation to others (Boulding, 1978). In fact, one must be able to see the other's image of life in order to communicate at all. The operative statement here is “I will do something or I will ask you to do something because of what I am and because of who you are.” This interaction is based upon the "roles" that individuals or groups play in society.

The important point to make here is that all human actions in society are an admixture of the three social organisers, Threat, Exchange, and Integration.

3. A “PARADIGM SHIFT” IN THINKING IS REQUIRED

I then draw upon the “paradigm-shifting” perspective of Thomas Kuhn (1962), who compared and contrasted the steady, accumulative outputs of evolutionary “everyday” scientific work operating under a unified paradigm to the quickly changing operation of revolutionary science-making in times of revolutionary paradigm shift. One shift that has occurred is what I have called the “analogue to digital” transition (Gilder, 2012; Gilder, 2013). Drivers of Present Change Requiring Paradigm Shift in Thinking (Gilder, 2012) include:

- *Technology*: Analogue to Digital transition allows greater spectrum capacity *and* data transmission/copying without added distortion.
- *Globalization*: Enabled by lower costs for more communicative traffic capacity (Moore’s Law), leading to more self-serve interfaces and off-shoring of telecommunication-based services.
- *Neo-liberal politics*: “There is No Alternative,” “End of History/Utopias”
- *More and more “scalable” “symbolic analyst” jobs* being subjected to “extremistan” market pressures (think pop stars and sports celebrities)
- *Move from “Doughnut Hole” Jobs to “Inverted Doughnut Hole” Jobs*, with less security and more stress for most workers.
- *“Unbundling” and “Deskilling”* of former professional “craft” (”free”) careers into “managed” semi-professional piece-work jobs.
- *The move of systemic “manufactured risk” from government to the individual* with “casino” promise of high returns for the lucky.

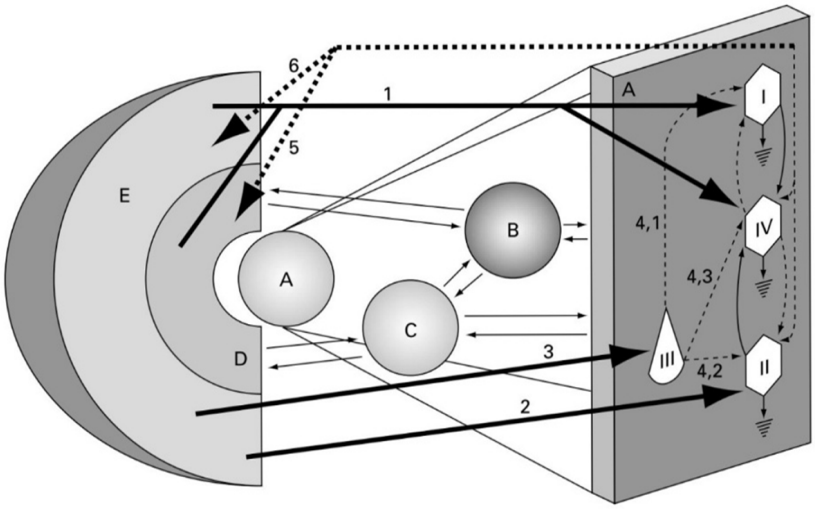
4. AN INTEGRATION OF NATURAL CAPITAL (NC) AND SOCIAL ECONOMIC SYSTEMS (SES) IN THE ECOLOGICAL HIERARCHY

As detailed in Gilder & Pal (2015a), Vadineanu (2001) provided a comprehensive model of our environment, which, in his words, “integrate[s] both the components of the Natural Capital and those of the Socio-Economic

Systems" into the "troposphere and in the HGMU [Hydro Geomorphic Unit]" (p. 315). Vadineanu categorizes these components in this fashion:

I. NC
A. Natural
B. Seminatural
II. SES
A. Human-dominated
B. Human-created

As Gilder & Pal observed (2015a):
Vadineanu's GST (General Systems Theory) approach colours his view of coming trends in both topics and approaches of ecological studies: "The relationships between «humans and nature» more recently referred to as 'development and environmental' relationships or between 'economy and ecology' should be further reformulated and recast as the mediated and dynamic relationships at local, regional and global scale between the structure and metabolism of Socio-Economic Systems, on one side, and the structure, productivity and carrying capacity of the natural, seminatural and human-dominated systems (NC), on the other side."



The general physical model of the socio-economic system and its relationships with Natural Capital.
A - The man-made physical capital: I - the infrastructure of the economic subsystem dependent on the renewable resources provided by the components of the Natural Capital; II - the industrial infrastructure of the economic subsystem dependent on «non-renewable» resources; III - Systems* for commercial energy production using as primary resources: fossil and nuclear fuels and hydro-power potential; IV - the human settlements infrastructure. B - Social capital; C - Cultural capital; D - Man-dominated components of the Natural Capital; E - natural and semi-natural components of thr Natural Capital: 1 - flow of renewable resources; 2 - flow of raw materials; 3 - flow of fossil and nuclear fuels; 4 - flows of electrical energy; 5 - material and energy inputs (fertilisation, pesticides, agrotechnical works, irrigation, selection etc.) to support tje management of man-dominated systems; 6 - dispersion of heat of secondary products (wastes) in the troposphere and in the HGMU components.

Figure 2 and caption Vadineanu's SES/NC Inter-Relational Model (2001, p. 25)

COMPONENTS OF THIS NECESSARY INTEGRATION FOR SUSTAINABILITY

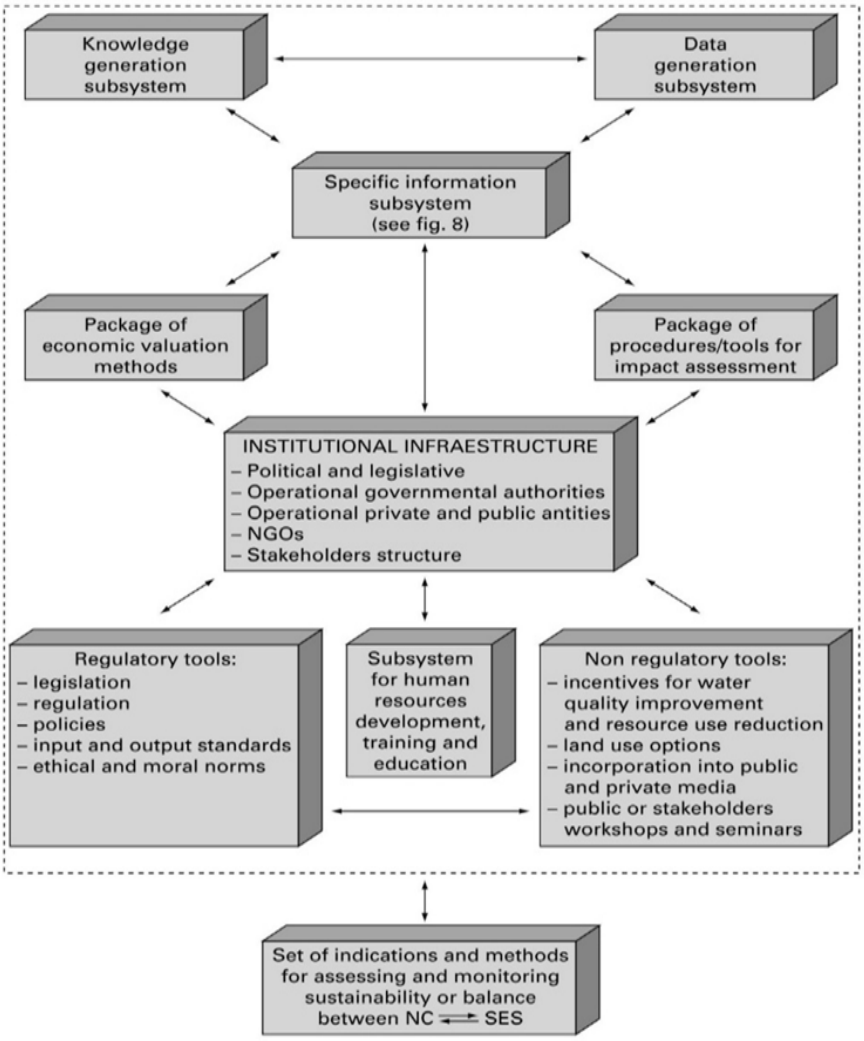
Vadineanu (2001) states, "according to the above statements, I use for the term 'biodiversity' the broader meaning which covers on one hand the components of Natural Capital together with their taxonomic and genetic diversity and on the other hand, human social organization, ethnic, linguistic and cultural diversity" (p. 23).

The basic components of integration necessary for achieving sustainability, Vadineanu claims, are four:

I. "The assessment of the conceptual and methodological approach of development, establishment of state of the art in the field as well as the main gaps and shortages and the needs for further development and improvement" (p. 20);
II. "Formulation of at least some of the basic elements of the dynamic model for 'Co-development' of socio-economic systems and Natural Capital/'Sustainable Socio-Economic development' to be used as the 'attractor' in the local, regional and global transition" (p. 20);
III. "Identification of the premises or advantages (opportunities) and the limits or constraints each country and region may rely on or be faced in the designing and implementation of long term 'co-development' strategies and action plans" (p. 20);
IV. "Identification of the existing shortages and gaps in the policy and decision-making process dealing with sustainability and formulation of a comprehensive and dynamic model for the 'decision support systems' as the interface or the operational infrastructure, the only one enabling us to balance the spatio-temporal relationships and the mass and energy exchanges between the Natural Capital Structure, serving as foot print and the Socio-Economic Systems " (p. 21).

5. VADINEANU'S DECISION SUPPORT SYSTEM (DSS) MODEL TO SUPPORT SES/NC INTEGRATION

Gilder and Pal (2015b, p. 92) noted that Vadineanu's (2001) Decision Support System (DSS) Model sought to balance, in his words, the "development of SES and NC or in other terms for 'integration ecology and economy' at different spatio-temporal scales" (p. 27).



The Structure of the Decision Support System for balancing the development of SES and NC or in other terms for «integration ecology and economy» at different spatio-temporal scales.

Figure 3 and caption Vadineanu (2001)

Adept use of this DSS model by policymakers will be required if Papua New Guinea and the other OACPS countries are to meet the SDG 7 Energy Goals. These indicators by target are:

7.1. "By 2030, ensure universal access to affordable, reliable and modern energy services;
7.2. By 2030, increase substantially the share of renewable energy in the global energy mix;
7.3. By 2030, double the global rate of improvement in energy efficiency" (Sdgcounting, 2016).

But, as Gilder & Pal (2015b) noted, too many policymakers (and the public) are deeply wedded in their daily life practices to fossil fuels; the social costs of enacting needed climate-change policies will be great:

Before Vadineanu's rational decision-making system (DSS) can be realistically implemented by policy makers, we all need to take heed of the danger of this public desensitization, and also realise that wilful blindness is in full operation among political and policy elites, given the overwhelming size of resources and fortunes tied to the continuing employment of "dirty" productive technologies.

Yet, in Papua New Guinea (where continuous power is still seen by many as a luxury good), real efforts to provide sustainable energy to remote villages have been undertaken, as noted by Lovo, et. al (2019). In their field research, "we assembled into a single hypothetical 'energy basket' all the varied renewable 'green' energy sources within PNG (as estimated by our energy research groups)." From this, they argued that, "there is sufficient renewable energy in PNG", and they further stated that, "these available green energy sources should be tapped, for they can go a long way in the quest for climate change mitigation" (p. 117).

CONCLUSIONS

Which SDG 7 Targets can be realistically met, given present SES conditions?

To conclude, as Gilder & Pal (2015b) recalled, "W.I. Thomas . . . wrote: ―It is not important whether or not the interpretation is correct—if men define situations as real, they are real in their consequences. . . . The key point of the Thomas Theorem is that an individual's beliefs or perceptions about a circumstance—regardless of their basis in actuality—will have an effect on the individual's related actions. Further, an individual's interpretation of a situation may gain meaning and be reinforced as a result of the actions associated with it, beyond any objective significance this interpretation may have" (p. 92). In an age of seemingly 'irrational' policy decisions by some countries calling into question international agreements such as the Paris climate change agreement, policymakers in PNG and the OACPS region need to devise realistically attainable energy policies supporting ecological sustainability that they can enact with partners (public and private) willing to take on the charge to work towards a liveable world for all.

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Youth of Today, Leaders of Tomorrow: A Political Rhetoric? A Critique on Employment Opportunities and Challenges for the Out-Of-School Youth in Papua New Guinea

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Abstract: Youth unemployment and underemployment for the out-of-school has been a contentious issue amongst the top ten challenges confronting successive governments in PNG since 1975. The prevailing illusion that those categories of youth are ably catered for and supported by the traditional social safety nets, and can survive by working on their customary land (about 90% unalienated land) is no longer a reality for many young people. A great majority of them have left school and are still searching for brighter opportunities in life away from the land. Often, they are regarded as the targets of anti-social behaviors and disorderly community make-ups. Governments therefore spend relentless time, efforts and resources to keep them at bay and locked them away to pave the way for societies to function orderly for the sake of those few who are at the helm of power and wealth.

Numerous legislative and policy reforms have had no significant impact on the lives and prosperity of that particular target group, apart from the National Youth Movement Programme (NYMP-1980-1990) which will be reflected-on later in this paper. The popular slogan: "Youth of today and Leaders of tomorrow will only materialize if appropriate opportunities are provided today for them to prepare well for tomorrow" . And this paper is a brief critique of what has transpired and should be done in light of the modern challenges that are already excluding them in the process of development.

Key words: Youth unemployment/underemployment; Papua New Guinea, Social safety nets; Rural/Urban divide; Policy recommendations

1. THE POPULATION OF YOUTH IN PAPUA NEW GUINEA

Youth in PNG is defined by age as those between the ages of 12-25 years old. It represents the age group who supposed to be at school, thereby continuing their education until they reach tertiary level and complete their final stages of education in our inherited formal education system. That youth population represented 28.8% (1/3) of the total population in the country between 1990 and 2000. (NSO, 2000)

In the same period of time, the national population growth rate was between 2.8-3.0% per annum, with the youth population also projected to increased at about the same rate. The implication therefore was that, both the state and the society in general were confronted with a mammoth task to create and provide productive activities for the growing number of young people. That includes creating employment opportunities within both the formal and informal sectors of the economy.

The 2000 National Population Census further reported that, the youth population of PNG below fifteen (15) years old represented 42% of the total population compared to the sixty (60) years and over age group where only 4% was recorded. It represented almost half of the nation's population and by 2010, they will be in their twenties (20s). Some of them may already have become parents by then. The average age of the population was projected to remain at the twenty (20) years mark in the first two (2) decades of the new millennium to the year 2020 (NSO, 2000).

Comparatively by world standards, PNG relatively has a young population with aging a less pressing issue during the same period of time. However, by 2020 onwards, aging has become an emerging social economic issue. The nation was not prepared to mitigate and facilitated relevant policy actions in social protection and social security to accommodate that category of the nation's population.

That scenario appears to loom as a double-header challenge for the relevant authorities. They must now wrestle with the continuing plight of the unemployed youth population, as well as meeting the needs of the emerging old age population. It will remain as the order of population growth and life cycle spiralling into the next millennium and beyond.

Tables 1-3 below highlights the trends of youth population growth of ages between 12-25 years in the urban and rural areas as noted in the Revised National Youth Policy 2007-2011.

Table 1: Youth Population in PNG 12-25 Years Old.

Age	**Males**	**Females**	**Total**
12-25 years old	778,070	717,104	1,495,174
Rural	660,406	613,956	1,274,362
Urban	117,664	103,148	220,612

Table 2: Rural Youth Population 12-25 Years Old

Age	**Males**	**Females**	**Total**
12-14 years old	168,833	147,315	316,148
15-19 years old	251,598	223,971	475,569
20-25 years old	239,975	242,670	482,645

Table 3: Urban Youth Population 12-25 Years Old

Age	**Males**	**Females**	**Total**
12-14 years old	23,081	21,156	44,237
15-19 years old	41,679	37,233	78,912
20-25 years old	52,904	44,759	97,663

Source: Second Revised National Youth Policy of PNG 2007-2011

2. YOUTH UNEMPLOYMENT

Youth Unemployment is defined as; "the share of the labour force ages 15-24 without work, but available and looking for employment" (https://www.macrotrends.net/global-metrics/countries/PNG/papua-new-guinea). Simply put, it refers to people who have met the requirements to gain an employment in the formal sector, but there is no work or job vacancy available for them in the labour market.

Youth unemployment has been a hot subject of discussions by successive governments in PNG for five decades. And real practical response to curbing with the unemployment and underemployment situation seemed to be diminishing as youth employable population increases by almost 3% every year. Despite numerous efforts since independence, youth unemployment continues to prevail as one of the major hinderance to development efforts in the country. And law enforcing authorities as well as the community at large often regarded it as law & order situations (Melpa, 2022). The underlying causes are rarely addressed.

According to the 2000 National Population Census, the Employment Rate remained at 2.8% in between 1990-2000. In 1990 the percentage of Formal and Subsistence/Semi-subsistence labour force stood at 18% and 74 % respectively, whilst unemployment was recorded at 8% of the total population (NSO, 2000).
Informal wage employment was recorded at 15% in 2003 and was expected to increase to 20% with the passing of the Informal Sector Bill in 2004.

A recent NRI (National Research Institute) report indicated that, youth unemployment represented 62% of the total population in 2020 (https://pngnri.org).
In recent years since 2019, youth unemployment rate has slightly improved and remains steady with a minimal increase in 2019 according to Macrotrends. https://www.macrotrends.net/global-metrics/countries/PNG/papua-new-guinea).

Without empirical data to substantiate these trends of development, the rare declining trend can be attributed to a number of factors. Such include the introduction of the government's *"leave no child behind'* policy in education which aimed to retain the school age children in the classroom until they reach grade 12 level of education.

In recent times, most Provincial Governments as well as individual Members of Parliament too have initiated school subsidy programmes for their respective electorates. These efforts bear mutual benefits to the politicians, as well as financial relief to the parents and sponsors

All those initiatives Culminated with the introduction of the HELP (Higher Education Loan Scheme) by the National Government for students attending tertiary institutions in the recent past. None of those efforts are aimed at the out-of-school youth population.

At this stage, there are no empirical evidence to link such education subsidies to the slide decline in youth unemployment as illustrated in Table 4 below.
The other assumption is the emergence of increasing number of private educational institutions and collages in the last decade which had provided additional spaces for potential school-leavers.
These efforts are not linked directly to creation of new jobs in the labour market for the youth population, nor is there any clear pathways to determining the demands of labour market with the number of graduates each year, especially at the tertiary level.

Our universities and colleges produce countless accountants, lawyers, engineers, social workers, teachers, doctors and other professionals anticipating the job market will provide them with employment opportunities after they graduate. They are not trained to return to the village and become rural village farmers or cultivate their land. That has its own social-cultural as well as legislative and policy implications.
On the contrary, they all graduate and seek white-collar jobs in both the public and private sectors, and increasingly today in the NGO sector as well.

Table 4 illustrates the youth unemployment rate in PNG between 2019 and 2023 highlighting a steady, but fluctuating scenario for that short period.

Table 4: Papua New Guinea Youth Unemployment Rate between 2019-2023

Period (in years)	% Rate	Increase by %	Decline by %	Comments
2019-2020	4.26	0.3		
2020-2021	4.08		0.18	
2021-2022	3.72		0.36	
2022-2023	3.70		0.02	

Experts estimate that as of the beginning of the new millennium, approximately 80,000 young people will leave school every year out of which only about 12.5 % are able to get absorbed into the formal labour force. And one third (1/3) of the total labour force is self-employed and found in the agricultural sector (Revised National Youth Policy, 2007-2011).

There is that inherent illusion amongst our leaders and policy makers that, the rural informal sector which makes up 87% of the population has, and will continue to sustain those who cannot be accommodated by the formal sector of the economy, including the projected 80,000 school leavers each year.

Such perception is contrary to the inherited education system which creates expectations and prepares the school leavers for white-collared jobs when they leave schooling at various levels of education. Very little emphasis is placed on rural, village-based life style in our existing education curriculums.

The 2000 National Population Census estimated that, the employment rate in PNG was at 2.8% which was equal to the annual national population growth rate. That means that every time when a new child is born, a

young man or women is added to the list of the unemployed, hence the state must create the employment opportunities for that new person.

The employment rate has remained at the same rate for almost two decades since early 1990s and was expected to remain at that rate to the end of 2010. In 1990 the percentage of formal and subsistence/semi-subsistence labour force stood at 18% and 74% respectively. Unemployment was recorded at 8% of the total population (NSO, 2000)

In the informal sector, the informal wage employment was 15% in 2003 and was expected to increase to 20% by the end of the first decade of the new millennium with the passing of the Informal Sector Bill in 2004.

3. GOVERNMENT EFFORTS TO ADDRESS YOUTH ENGAGEMENT AND PARTICIPATION IN NATION - BUILDING SINCE INDEPENDENCE FOR THE OUT-OF-SCHOOL YOUTH POPULATION

The very first government policy on youth development, the National Youth Policy of Papua New Guinea was adopted by the National Executive Council in 1983.

Ten (10) years later in 1993, the NEC through its Decision No. 114/93 directed the National Youth Commission to review that Policy together with the NYC Act 1991. This review was necessary to streamline youth development programmes with the political and administrative structural reforms in the country at that time. The consequent outcome was the adoption of the Revised National Youth Policy by Parliament in January 1997, followed by the enactment of the National Youth Commission Bill two (2) years later in December 1999 (Wrondimi Review Report, May 2006)

The Bill then provided for the establishment of the office of the National Youth Commission which became the central government agency responsible for youth development work in the country. The National Youth Policy was revised once again six (6) years later in 2003, this time with greater focus on the roles and responsibilities of the Commission in order to reflect and realign with the reforms.

The review was also necessary to accommodate the changing needs of the youth population and the society at large ten (10) years after 1993.

3.1 The National Youth Movement Programme (NYMP)

The PNG Government's first practical initiative for the out-of-school youth populations was the establishment of the National Youth Movement Programme (NYMP) in the early 1980s and parked under the Prime Minister's Department. It was just an office which also accommodated the Women, Sports & Recreation, and Religion functions, and officially known then as the; Office of Youth, Women, Religion, Sports & Recreation (Wrondimi Review Report, May 2006)

The fact that the NYPM was located directly under the Department and Ministry of the Prime Minster himself, coupled with the appointment of a senior Satesman in the form of the late, Bernard Narokobi as the founding Charman of the nation's youth council network was a symbolic gesture of priority accorded to harnessing and involving young talents in the process of nation-building, as well as an inclusive, participatory, development approach by the post-independence Somare-led government.

NYMP's programmes and activities were centered around the three main themes of Mobilization, Participation, and Productiveness. The principal goal was to mobilize the (mainly out of school) youth into manageable groups of between 15-30 members, have the groups registered, then engage them in productive activities, hence contributing meaningfully to the development process.

To realize those three themes or pillars, the your activities were align under five components, which included; i) the Youth Council Network, aimed at providing a forum for them to address issues affecting them, ii) the Grants Scheme, to engage them in productive self-employment activities, iii) the Youth Training Programmes, to train them in various leadership and organisational knowledge and skills, iv) the Youth Shows, to provide avenues for the youth to display their talents in productive economic and cultural activities, and, iv) the Community Youth Co-ordinators (CYC) Scheme, where outstanding young people were identified and appointed to co-ordinate youth activities at community level. They were place on regular allowances of K80.00 per month (Wrondimi, 2006)

To compliment those initiatives, I collaborated with Mr. John Honani from the National Broadcasting Commission (NBC) and initiated a weekly one-hour programme for the young people known as *"youth of today'* in 1985. The live broadcast provided an avenue for the young people to call up and discuss any issue of concern which they wanted to share with one another to even to express matters concerning the plight of the young people to the government and other relevant stakeholders. I was then the Youth Coordinator for National Capital District Urban Youth Programme, the urban component of the National Youth Movement Programme.

- ***Reflection on the Impacts of NYMP between 1980-1990***

After 45 years on (2025 now), and NYMP still remains as the most successful youth development programme in the country in terms of mobilizing the unemployed, underemployed and out-of-school young people to meaningfully engage in, and constructively contribute to community and nation-building at that time.

By the time when NYMP was replaced with the then, National Youth Service (NYC Act 1991), the former was fully established with a nation-wide youth council network comprising a National Youth Council, 20 Provincial Youth Councils, 97 District Youth Councils, over 10 Urban Youth Councils in the ten selected major urban centres, and a good number of Area Youth Associations at the sub-district levels (Wrondimi, 2006)

At the peak of its existence after ten years of operation in 1989, over 30,000 youth groups were registered amassing an estimated 300,000 youth population throughout the country. It was the largest youth movement programme in the short history of the nation, and the first of its type in the entire Pacific Region. Many island nations in the region were beginning to emulate the youth development model which was already making news headlines as an alternative voice for the voiceless youth population who were very vulnerable to the inevitable influences of modernization in the globally changing world.

The youth councils offered the only forum for the young people to meet regularly and discuss issues affecting them in the seemingly uncaring world pertaining to their advancement in life. It provided the only legal avenue through which they were able to discuss issues, share experience of common interest, and safely express their views and concerns for greater participation in the development process.

It further provided the avenues for them to develop their leadership and organisational skills, which enabled some of them to become provincial and national leaders like (the late Albert Mokai, Premier for Southern Highlands), and Greg Maisen (Deputy Premier for East Sepik Province) to name a few. They both were community youth workers under the NYMP's Community Youth Coordinators Scheme, and later became chairpersons of their respective Provincial Youth Councils in the late-1980s.

More than 300 you leaders were trained and certified as qualified community youth workers at the YMCA training centre in Lae. About 50 of them advanced to received their Diplomas in Youth and Development at FIJI after completing two years of advanced studies in youth and development.

Many more young people benefited from the NYMP Grant Scheme where project grants worth K1000 (maximum) were made available to fund successful youth projects. Such benefits were not all monetary, but in-kind as well including transfer of new knowledge and skills in project planning and management, budgeting, accounting, and the whole concept of entrepreneurship.

The Annual Provincial and Regional Youth Shows also provided windows of opportunities for the young people by bringing together people from all walks of life to congregate, interact, show case their youth talents, as well as getting to know each other and share experiences and skills between and among one another.

3.2 The National Youth Service Act (1991)

The National Youth Service (NYS) Act of 1991 replaced the NYMP which promoted both continuity and diversion on youth development work in the country. Whilst consolidating the initial youth network which was established under the ousted NYMP, it also provided a new dimension which was aimed at engaging the young people as volunteers in close allegiance with the disciplinary forces as their trainers and supervisors.

The main emphasis of NYS was on Network Strengthening, Total Participation and Advancement (NYS Act, 1991) which was basically to continue from the benchmark that was already set under the previous programme (NYMP).

The main goal for the young people to be involved in the construction of infrastructure facilities and engage in community service activities under the close supervision of the disciplinary forces (which was the original intention of the new NYS Act} never eventuated. Instead, a Youth Brigade Scheme was initiated and piloted in several major urban centres like Port Moresby, Mount Hagen and Lae where the unemployed young people were mobilized and trained by members of the three disciplinary forces to provide security services to individuals, business houses and public facilities in and around the cities.

In return for their services, some payment in both cash and in kind were made to the NYS offices, some of which was later redistributed to the youths as their wages and allowances. I coordinated the Lae programme for a short period of time from October 1992 to July 1993. In Augus 1993, I joined the University of Papua New Guinea as an academic and has remained in that profession since then.

The whole idea under both youth programmes was to provide alternative opportunities for the unemployed and underemployed out-of-scchool young people in the informal sector, both to keep them occupied, as well as to create avenues for them to participate in and make meaningful contribution to the nation's development process.

3.3 The National Youth Commission Bill (1999)

The government's further reform in youth related work took place in 1997 which resulted in the passing of the National Youth Commission Bill (1999), and the subsequent development of the Draft National Youth Policy 2007-2011 of Papua New Guinea in 2006.

The main emphasize of that revised youth policy was on Massive Participation, Rural Development, Decentralization, Integration, Democratization, Volunteerism and Unity, among both the service providers and youth themselves at all levels and across all sectors of society (Wrondimi Review Report, May 2006).
It further paved the way for the establishment of the National Youth Commission which became the official government agency responsible for all youth related matters in the country.

The National Youth Commission had wide ranging powers and function, so much of which has not been fully or effectively implemented during the first six years of existence. It was entrusted with eight major functions under section 4 (1) of the Bill. These included the following:

- To co-ordinate policy development on youth matters, provide policy advice to Provincial and LLGs on government matters pertaining to youth, identify and provide training opportunities for both youth workers as well as the youth population, facilitate efficient research on youth matters, provide technical specialists to Provincial and Local Level Governments, establish standards and reinforce and monitor level of youth service across all sectors, monitor youth development plans at all levels, and provide opportunities for youth participation at international as well as aid activities within the Country at all levels (Wrondimi, 2006)

- ***Reflection***

Despite all these latter government legislative and policy reforms in the years since the abolition of NYMP in 1990, the youth population still remain untouched and disengaged right across the nation as participants, beneficiaries and the primary target group of those government efforts.

There is currently a huge cap between policy making and policy implementation. All benefits appeared to be enjoyed by the bureaucrats who conduct numerous conferences, workshops and seminars hence using funds for youth work for their own travel logistics and allowances, as well as for their wages.

One of the contributing factors to the creation of that communication and implementation gap are the various provisions in the Provincial and Local Level Government Act (1995) which the national youth office continuously applies as an excuse to justify its stand that, ***its function is to make policies only. It is the role of the lower lever governments to implement the policies.***

In my view the Act should be reviewed and such inhibiting provisions be repealed because the practical reality on the ground does not reflect the purpose and original intentions of the Act today. It is indeed the main contributor to the lack of collaborative efforts by the three-tier government system in the delivery of services, not only for the youth population, but the wider rural communities throughout the nation.

3.4 The Introduction of Youth Wage

Amongst many earlier measures taken to address the youth unemployment situation in the country since independence, the government through the then Department of Labour & Employment under the Minimum Wages Board made a historical decision to include National Youth Wage for new entrants into the labour force for the ages between 16-21 years old at 75% of adult minimum wage (Department of Labour and Employment, 2000).
It was an inclusive decision for both the adult and the youth employees under the National Minimum Wage structure, and was applauded by many youth employer organisations and agencies across the nation, especially churches and NGOs who were already engaging the youth in greater numbers under voluntary or temporary wage arrangements.

However, in less then a year, the government of the day resented the MWB decision and reverted back to the 1992 National Minimum Wages which has remained since then. It excluded the youth population as a special category of workforce who deserved such a recognition. It was a regressive decision, and a slap in the face for the employable young people in their new hopes for a fare share of the cake in the nation's paid labour market.
Among many other reasons, the reversal of the MWB was attributed to the argument that, the demands by the workers were beyond the employers' financial capacities to comply. Simply put, the employers could not afford to implement the new MWB's decision. The Government using its veto power was sympathetic to the employers and disallowed the decision when the workers walked out of the determination hearing in protest, subsequently reverting back to the Minimum Wage Rates of the 1992 Determination.

In 2003, a Supplementary Minimum Wage Agreement was reached between the Employers Federation of PNG (acting on behalf of the employers) and the PNG Trade Union Congress (acting on behalf of the workers), which was registered as Award No.11 of 2003. This Award has allowed for a uniform Wage rate for all the youths right across the country, which was consistent with the intentions of the Award to generalize this Award to all the workers, outside of PNGTUC and the EFPNG memberships.

The new Interim Minimum Wage (which replaced the 1992 Minimum Wage, until a new Minimum Wage rate is agreed to) is K37.20/week or K74.40/fortnight. "The new National Youth Wage therefore shall be 75% of the proposed new Interim National Minimum Wage and shall be applied to all new entrants to wage employment between 16 and 18 years" (MOA of the Award No.11 of 2003)
In 2004 the government passed the Non-Formal Sector Bill which recognises and promotes the involvement of the 85% of the population in the development process through the informal sector activities. It is thus expected that many more young people will be involved in unskilled, self-employed activities to benefit themselves and their families and communities.

The government at that time also committed to spend over PNGK346.9 million on Income Earning Opportunities alone in the next three years between 2005-2007 (MTDS 2005-2010). Such initiative aimed to boost the employment rate as well as the overall GDP to higher levels in the medium and long term if the economy growth continues to remain steady at its current level.

In the nutshell, the government of PNG has given political recognition and support in terms of legislations and policies on youth development for two (2) and half (½) decades since 1980.
Regardless of all its efforts, there are no specific youth employment or employment-oriented programmes targeted at the out-of-school young people alone, so that they can clearly identify with and participate in it since the 1990s. Neither are there any combined youth employment programmes between the various sectors which are restricted only for the young people. In a very competitive labour market, the young people are the least fortunate and often get missed out for lack of experience, mistrust and nowadays for not knowing the *" buddies"* in the system.

3.5 Factors Affecting the Employment Situation of Youth in PNG

The common factors affecting the employment situation in this country has some similarities to those in other Pacific countries. Those that are unique to Papua New Guinea context, and hence requires greater attention by decision-makers, policy- makers, and youth workers are highlighted in the ensuing discussions.
According to Wrondimi (2008), the following were some of the main factors affecting youth employment activities in this country;

- ***Global influences***

The inheritance of the global free market economy has increased social problems around the world, mainly in the developing and third world countries like Papua New Guinea. There is now an increasing gap emerging whereby the income distribution is concentrated at the top 5% of the wealthy population thus affecting the redistribution of limited resources to benefit the majority. Employment creation has thus become a low priority of government in this country since the 1990s while it concentrates on meeting the demands of the well-to-do citizens in the multinational corporate and private sector agencies.

Globalisation has also increased marginalisation of labour and the poor thereby increasing community Balkanization and rapid loss of community cohesion in some parts of the country. Many young people too are now finding it difficult to identify themselves with a community, let alone being accepted by one, as none seemed to be found wanting for an increasing number of them, particularly those come from cross-cultural marriages. They are constantly being disoriented from their roots of origin hence language and cultural identity.

It has also widened gaps in education, skills transfer as well as income and wealth generation opportunities for the majority young people with greater emphasis placed on meeting the needs of the global market economy and facilitate investor confidence.

The formal education system which was inherited at independence has proven to be of less employment benefits to the great majority of young people. By the turn of the century, only about 15%-20% of them were able to find jobs in the formal sector (NSO, 2011).

Modern technology has also placed many more people out of jobs worldwide and PNG is no exception. Unlike 20 years in retrospect, a government department which employed ten secretaries and typists can today employ only five because the computers can double the manned hours as well as the amount of workload required compared to the ordinary typewriters in the past.

- ***PNG Context***

Papua New Guinea is proclaimed by many as a unique country rich in language and cultural diversity, and yet remain unified as" *one nation, one country and one people*". It is sometimes confusing for an outsider to fully understand and comprehend some of the cultural behaviour and attitudes of people from that perspective, especially when some of such have now been integrated into the workforce and blended as acceptable work place behaviours and practices.

At the upper rung of the leadership scale, the nation's leaders pass legislations and create policies, much of which do not necessarily control and regulate the citizens' lives in a strict and rigid way as one would normally find in well structured modernized societies. Neither are the implementors fully committed to seriously implement the policy decisions to realise the anticipated outcomes, let alone policies on youth employment and unemployment.

In that context there has been so much rhetoric on the creation of youth employment opportunities as preventive measures to alleviate escalating law and order issues since the 1980s. The reality has been a very slow progress, often passing on the burden to the corporate and private sectors as well as churches and NGOs to find the answers.

Government agencies which are responsible for youth matters seemingly take a backseat and expect the former to implement those youth policies and plans on their behalf, rather than to be at the forefront and taking the lead. The prevailing excuses of *"lack of funds"* seemed to be unceasing and has found a permanent place in our modern workforce.

Such *"taking the back seat"* approached are often reflected in instances when, if there is a crime associated with youth, everyone in the society becomes emotionally involved in the debate on the types of measures (including youth employment programmes) that should be taken to deal with the situation in the spur of the moment. As days, weeks, months and years passed by the whole subject becomes a non issue until it occurs again.

Responsible state agencies often align with the law enforcing agencies to address it as a law & order matter without attempting to investigate the underlying issues that compels the young people to resort to such actions. Reactionary measures also continue to prevail in other areas such as domestic violence, violence against

women and girls, and white-collar crimes, regardless of the relevant laws that are already in place to create and enforce proactive measures.

In fact, every other form of expression has now become a police matter, tightly controlled and restricted to safeguard the interest of the government of the day. Even public gatherings and expression of public opinions as people's participation in what was once a "free-flowing democracy" has now been suppressed and sanctioned by a seemingly authoritarian government that is so adamant to stay in power for whatever it takes.

The young people have no space at all in such *"controlled rooms"* to express their desires and expectations as equal players in the nation's playing field on matters of development and progress in so far as their interests are concerned.

Traditionally, young people in PNG are not resource owners and decision-makers without the consent of their parents, clan members or community leaders. They find it very difficult to make independent decisions on the use of resources such as land, material and even youth labour to perform self-help, self-employment activities without parental or community approval.

Their image in the society's social structure has also been tainted by the criminal activities of a few over the years. Generally, they cannot be trusted by many potential employers hence get turn down mostly on unskilled jobs which they are more than capable of performing.

The government and the society as a whole are not keeping pace with the changes which are affecting the lives of the youth of today. Their values, preferences and expectations towards modern lifestyle are changing so rapidly which makes it even harder for the policy makers to make the right choices on their behalf.

For instance, they cannot be forced by the government's *"rural shift"* policies to return home to tilt their land after completing their university studies when their colleagues could find white collar jobs in the formal sector and live a decent life in the urban environment. This could only happen when the employment conditions as well as the general lifestyle in the rural areas had been improved.

At present the young people have no forum to collectively raise issues and concerns affecting their lives in the country. The National Youth Council has not been revived for almost three decades now, although they are required by law to have that body representing them.

In PNG there is no way of determining the linkage between education and employment in both the formal and informal sectors. Young people who undertaking various courses do so with the hope that they will manage to find a job somewhere, somehow when they graduate. There is very little or no data currently available which indicates the creating of new jobs in the labour market for each profession, be it for accountants, lawyers, architects, social workers, doctors, teachers, so on and so forth.

The other common obstacle confronting the young people who leave school each year is the inherent employer culture which generally regard them as having lack of experience to perform to their expectations. Almost 99/100 times the potential employers would mention *"previous experience"* in the job advertisement which immediately turns off an applicant's interest.

4. CONCLUSION

The issue of youth employment or unemployment (and underemployment for that matter) has been top on the list of government concerns and debates over the years. Much of it were just mere rhetoric without constructive actions.

Whilst there have been some positive responses in terms of legislations and policies, reforms these are mostly about general aspects of youth development work. They act as governments guidelines for other sectors to refer to as the point of reference for youth development work.

There is at this stage no specific employment scheme or programme in PNG which are targeted at the young people alone. They have to compete with the adults in the open job market which has proven to be to their disadvantaged in most cases.

With the government's "downsizing and streamlining exercise" during the beginning of the new millennium, particularly under the public sector reforms, there was an indefinite freezing on the creating of new jobs right across the board. Only the private and corporate sectors are still creating some job opportunities for the new entrees into the labour force. The nation has experienced a long period of recovery from then on until now to

cerate something tangible and constructive for the youth population in terms of employment opportunities, particularly in the formal sector of the economy.

In a small economy where the employment growth rate is just beginning to pick up at a slow rate of 3% in the four years since then, only a handful of industries such as mining, logging, fisheries, canneries, security services and the building industry seemed to be creating new job opportunities for the labour market.

Even then there is insufficient data readily available to justify and confirm the actual number and rate of job creating per sector or industry at this stage. A more comprehensive study is overdue to provide updated information on the youth employment situation the country. The recently completed NSO data from the national population census (2024) has yet to be processed for public consumption.

The government's commitment to spend over PNGK346.9 million on Income Earning Opportunities alone during the years between 2005-2007 initiative was aimed to boost employment rate as well as the overall GDP to higher levels in the medium and long term if the economy growth continued to remain steady at its current level (MTDS 2005-2010).

Again, such initiatives are not targeted specifically at the youth population but on the wider labour force. The young people will continuously be placed at the disadvantaged position due to lack of experience and general lack of trust from the potential employers.

Other factors such as lack of consultation by line agencies such as the National Youth Development Athority and the Department of Labour & Industrial Relations regarding employment related matters for young people must also remain as a concern for now. They must work together to find or create such opportunities within the small and very competitive job market, and more so in the informal sector of the economy.

The National Youth Development Authority has been silent for nearly two decades which has a trickled-down effect on the youth population throughout the nation. Policies are been repeatedly developed and procrastinated over the years with no tangible benefits to the young people of the nation. There is currently no linkage or connection between policy-making and implementation at the ground level. The policies are just floating as political propaganda for the Youth Development Authority and its collaborators at the national level. The greatest danger is that, the longer we procrastinate, the harder it will become for the nation and the society as a whole to catch up or cope with the ever-changing needs of the youth population in the years ahead.

5. PROSPECTS AND OPPORTUNITIES GOING FORWARD

The modern economy and general trend in the global movement of changes have created much broader and wider scope of opportunities as well as prospects for the unskilled and semi-skill youth to be gainfully engaged in the labour market at various levels and sectors of society. And in that context, PNG is no exception.
The following employment opportunities are recommended for the out-of-school in this country going forward;

5.1 Reintroduction of the NYMP Model of Youth Development

An NYMP-type youth development model should be devised to suit the current and changing needs of the youth population. More so, the Youth Council Network must be reactivated and re-established to provide legally safe avenue for the young people to make decisions, plan and perform various activities of interests to them. They need a space to congregate, share issues and concerns of common nature, and express such collectively to the leaders of the nation.

The commonly expressed rhetoric of *"youth of today and leaders of tomorrow"* will only materialize when such avenues are provided for the young people to practice their leadership skills today.

The currently held *"3rd Youth Parliament"* (EMTV News 15th December 2025) is a foreign concept which can find its proper grounding if a home-grown forum exist to facilitate is long-term survival. PNG cannot continue to rely on outsiders to clean up its backyards. The practices of *"here today and gone tomorrow"* must ceased completely in the next 50 years.

"Conventional youth policies and approaches undertaken to date (especially by outsiders) have proven to be ineffective to address the vast needs of this group" (Sonya Woo, quoted by Gedion Timothy in https:www.developmentaid.org/news).

5.2 Youth Brigades

Security Services is a booming industry in PNG today. The government through its agent the National Youth Development Authority should reintroduce the concept of "Youth Brigade Scheme" and engage the disciplinary forces to train the young people and deploy them in soft controlled environments such as at schools, hospitals, and individual households. An advantage here is that, they know their own kind and the respective networks, hence can deter any potential criminal activities that are being orchestrated by the criminal elements of society.
Through peer group relations and influence, such gangsters may eventually be co-opted into the youth brigade scheme as well.

5.3 Youth Farming

Through collaborative engagements by relevant stakeholders (NYDA, Department of Agriculture, Land Owners, and the Development Partners (both national and international), unalienated customary land can be freed up by the clans for youth in their respective villages and communities to be engaged in vegetable farming and livestock projects.
With basic farming knowledge and skills transfer, farming tools and marketing outlets provided, there is a huge potential for the youth to tilt their land and live-off its potential income-generation benefits.

5.4 Youth Engagement in Incorporated Land Group (ILG) Registration

The Incorporated Land Group (ILG) registration is now becoming a mammoth task for many Members of Parliament and their electoral officers. Young people who have completed their grades ten and twelve can be easily trained and engaged to perform that task with the close supervision of the relevant government officers or proxies of the government.

Such initiatives are suitable for the youth who originated from villages and rural communities that have direct contacts with their respective land owners and clan leaders. They can easily communicate with them and complete the required forms on behalf of the local MPs or the office of the Registrar of the ILGs in the country.

5.5 Seasonal Workers Scheme (Australia and New Zealand)

Priority for the Season Workers Scheme under the bilateral arrangements with the governments of Australia and New Zealand should be given to the out-of-school youth. They have untapped energy, enthusiasm and thrive to be engaged in such ventures. Many of them may not have started families of their own to tie them down, are free and flexible to stay committed to such employment opportunities.

Most importantly, they still have a longer life cycle wherein they can share and impart the knowledge and skills acquired under such exposer with fellow youths as well as to apply them in community and nation-building when they returned.

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Guerrilla Marketing for Island Sustainability: Small Actions Driving Big Impacts

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Abstract: Island communities face unique sustainability challenges, including resource scarcity, waste management difficulties, and vulnerability to climate change. Traditional awareness campaigns often fail to engage these communities effectively due to high costs and limited reach. Guerrilla marketing, an unconventional, low-cost marketing strategy, offers a promising alternative to inspire sustainable behaviours and practices. This short communication explores how guerrilla marketing techniques can be adapted for sustainable island living. By leveraging local culture, materials, and creativity, such campaigns can generate strong community participation and environmental awareness. Examples such as beach art installations from litter, pop-up recycling hubs, and solar lantern festivals illustrate the potential of guerrilla marketing in fostering eco-friendly behaviours. A conceptual framework is proposed to guide stakeholders in implementing these strategies. The article concludes by highlighting the need for pilot projects and further research to evaluate the effectiveness of such interventions in island settings.

Keywords: Sustainability; Guerrilla Marketing; Small Island Communities; Environmental Behavior Change; Resource Scarcity.

1 INTRODUCTION

Climate change, rapid urbanization, and resource constraints have led small island communities worldwide to face escalating environmental challenges, including coastal erosion, waste accumulation, freshwater scarcity, and reliance on imported fossil fuels, highlighting the urgent need for sustainable living practices. High costs, generic messaging, and cultural disconnects are some of the factors because of which conventional environmental campaigns often fail to resonate with these communities. As per United Nations Development Program Bangladesh (2024), the balance of life of the people living in this area are being ruined due to the river-erosion and salinity intrusion along with the climate change. Separation from the mainland because of surrounding oceans less frequently disrupts and diminishes normal life and the everyday activities of inhabitants' small islands, and in some cases allow for the sustained practice of traditional activities that impact positively on sustainability efforts. Residents of small islands may unintentionally harm their environment through everyday practices. While overfishing destroy the balance of marine ecosystem (EcoBlvd, 2024), cutting the mangrove forest weaken the defense against the storm and erosion (Tidal Basin Group, 2023). Improper waste disposal is another facet the small islander practice throughout dumping trash into the water, while burning plastics, pollutes land and water,

threatening wildlife and human health (Geetha & Rajalakshmi, 2020). Soil erosion and loss of biodiversity which are common in the small islands are triggered due to the unjustifiable farming and construction practices. These harmful practices are in rise because of the limited resources and lack of awareness or alternatives. Raising awareness among residents about these unsustainable practices could help protect the islands from gradual environmental degradation. To aware the residents a sustainable, memorable and innovative ideas to be utilized so that the residents at one stage habitually refrain from the erroneous acts. Guerilla marketing tactics, with their simple and memorable approaches, can create lasting impressions on residents, encouraging them to adopt sustainable practices to protect their fragile environment. Guerrilla marketing, an innovative marketing strategy known for its unconventional and low-budget approach, offers a promising avenue to engage island residents and visitors in sustainability efforts (BRAME, 2023). This can be achieved, for example, through exciting street art, pop-up events, flash mobs, or social media campaigns (Arsolon, 2025). By leveraging surprise, creativity, and community participation, guerrilla campaigns can deliver strong, memorable messages with minimal financial input. This paper introduces the concept of guerrilla marketing for sustainable island living and explores its potential to drive environmental awareness and behavior change through small-scale, high-impact actions.

2 GUERRILLA MARKETING AND SUSTAINABILITY: CONCEPTUAL LINK

Guerrilla marketing emphasizes creativity over traditional promotional methods, using unexpected and memorable tactics to engage audiences. Some of the guerrilla marketing campaigns such as street art promoting recycling or flash mobs advocating climate action has already been applied to urban sustainability campaigns. Guerrilla marketing and sustainability are two terms pose a common goal of achieving big results with minimal resources (Susilo, 2020, Mazumder, T.I., 2025). Guerrilla marketing relies on creative, low-cost, high-impact strategies that make the most of limited budgets, an approach perfectly suited to promoting sustainability (Erdem, 2025). Guerrilla marketing by using surprising, engaging, and community-focused campaigns, businesses and organizations can raise awareness about environmental issues, encourage responsible behavior, and inspire collective action without heavy spending or waste (Valont, 2025).

This collaboration makes guerrilla marketing an ideal tool for socializing sustainable practices, especially in resource-limited settings like small islands, where every small action can lead to a big positive impact (Ahmed et al., 2020). While traditional marketing relies on large budgets, mass media, and resource-intensive campaigns that can have high environmental costs, guerrilla marketing uses creativity, surprise, and local engagement to deliver a strong message with minimal resources and waste (Purr Marketing & Design, 2024). This low-cost, low-impact strategy aligns with the core values of sustainability: conserving resources, reducing waste, and maximizing social impact. Guerrilla tactics can be effectually used to encourage sustainable performances by creating unforgettable and attractive campaigns (Petraškienė, 2024).

These tactics, often characterized by their creativity, surprise, and limited resources, can be tailored to encourage actions like recycling, energy conservation, and biodiversity protection. Street art, pop-up events, and social media challenges can raise environmental awareness and encourage community participation without the need for expensive or wasteful materials. Guerrilla marketing also promotes local purposes, allowing communities to foster ideas appropriate to their own cultural and environmental contexts. Eventually, it is revealed that guerrilla marketing is not just a cost-saving approach—it's a method to model the very sustainability principles it promotes (Ahmed et al., 2020). By demonstrating creativity, resourcefulness, and community spirit, it offers an authentic, powerful tool for advancing sustainability goals in a world that urgently needs them. In island settings, guerrilla marketing is particularly relevant because resource limitations require low-cost interventions, community-centric culture enables participatory campaigns, and tourism dependency provides opportunities to influence both locals and visitors (Susilo, 2020).

Table 1. Comparison of Guerrilla Marketing and Conventional Environmental Campaigns in Island Communities

Feature	Guerrilla Marketing	Conventional Campaigns
Cost	Low	Moderate to High
Reach	Local, viral potential	Targeted, often limited
Engagement	High (interactive, participatory)	Moderate (passive audiences)
Cultural Adaptability	Strong (can use local art/tradition)	Moderate
Sustainability Impact	Incremental but visible	Broader but harder to measure

3 ISLAND HARM BY INHABITANTS

Islanders can harm the peaceful coexistence of the island in many ways, including overfishing that depletes marine life, cutting down protective mangroves, improper waste disposal that pollutes land and water, and unsustainable farming or construction practices that lead to erosion and habitat loss. Deforestation is being done by uprooting the trees for timber, cultivating land for agriculture (including livestock), and other activities leading to urban expansion can lead to the obliteration of forests and other vital ecosystems, dropping biodiversity and rising erosion (Fernández-Palacios et al., 2021). Draining wetlands for development or agricultural purpose can upset natural water cycles and habitats, leading to augmented flooding and loss of biodiversity (Lacey, 2024). Mining activities, particularly those for valuable resources like phosphate or minerals, can lead noteworthy landscape alteration and effluence (Worlanyo & Jiangfeng, 2021). As global temperatures are rising, sea levels are also rising, intimidating to submerge low-lying islands and coastal areas (Dickinson, 2024). Intensity of storms, cyclones, and floods can create widespread damage of infrastructure, homes, and ecosystems (Furtak & Wolińska, 2023). Enhanced preoccupation of carbon dioxide by the ocean can cause to ocean acidification, harming marine life, including coral reefs, which are very important for island ecosystems (Coral Reef Alliance, 2025).

Industrial events, such as production or mining, can release pollutants into the air, water, and soil, indulging both human health and the environment (Ruba, Chakma, Senthi, & Rahman, 2024). Inadequate waste management practices can cause to contamination of land and water resources, disturbing both human health and the environment (Environment and Climate Change Canada, 2024). . Unsustainable fishing activities can exhaust fish stocks, affecting marine ecosystems and food security (Walsh, 2023). Over-cultivation of land can lead to soil corrosion and nutrient exhaustion, reducing agricultural productivity (Begum, 2021). Though tourism in the small island may be a source of income, it can also cause to environmental impairment through enlarged waste, pollution, and habitat destruction (Baloch et al., 2022). In some cases, increased density of population may stress resources and infrastructure, leading to increased environmental pressures (Vetrivel, Vetrivel, Ilango, & Devarajan, 2024).

There are examples where the inhabitants of small islands have degraded their environment to such an extent that they were eventually forced to abandon the islands. In Banaba (Ocean Island) phosphate mining has devastated the island's surface, rendering much of it uninhabitable (Treagus, 2021). In Tuvalu rising sea levels and increased storm surges are threatening to submerge the island nation (Giordano, 2024). In Maldives the government's efforts to reclaim land from the sea, including dredging and sand pumping, may have long-term negative consequences for the island's ecosystem and its ability to withstand rising sea levels (United Nations Maldives, 2024). In Nauru Phosphate mining and the subsequent mismanagement of resources led to economic and social collapse (Rajaram, 2023).

4 PROPOSED APPLICATIONS OF GUERRILLA MARKETING IN ISLAND COMMUNITIES

4.1 Beach Art Installations from Marine Litter

Artists and volunteers create sculptures or murals using plastic waste collected from beaches. These installations raise awareness of marine pollution while beautifying public spaces. Art installations created from marine litter

can transform waste into powerful visual messages that raise awareness about ocean pollution while beautifying public spaces (Figure 1). These installations serve both as environmental education tools and as community engagement strategies.

Figure 1. Beach art installation created from collected marine litter. This guerrilla marketing tactic highlights the issue of ocean pollution and promotes sustainable waste management behaviors [(StockCake. (n.d.). Beach litter sculpture. StockCake. https://stockcake.com/i/beach-litter-sculpture_1199005_361217)]

4.2 Pop-Up Recycling Hubs

Temporary, eye-catching recycling stations made from locally sourced materials encourage residents and tourists to sort waste effectively. These can be coupled with gamified rewards (e.g., vouchers for local businesses). Pop-up recycling hubs, designed from locally sourced materials and paired with gamified incentives, offer a creative and temporary solution to encourage waste segregation and recycling (Figure 2). These hubs attract both residents and tourists, fostering participatory environmental action.

Figure 2. A pop-up recycling hub constructed using local materials to encourage community participation in waste management. Such installations can be coupled with reward systems to reinforce sustainable behaviors.

4.3 Solar Lantern Festivals

A solar lantern festival is a community event where residents exchange solar lanterns, culminating in a lantern-lit night celebration. This will encourage use of renewable energy and lessens plastic waste.

4.4 Rainwater Harvesting Murals

Arrangement for murals painted on water tanks and rooftops will portray traditional water conservation practices, sparking interest in rainwater harvesting.

4.5 Flash Mobs

Surprise flash mobs can be organized to depict the importance of recycling or conserving energy, generating a buzz and encouraging participation.

4.6 Guerrilla Gardening

Neglected urban spaces can be transformed into vibrant gardens, promoting biodiversity and sustainable food practices in an impactful way.

4.7 Interactive Installations

Making momentary, eye-catching installations in public spaces that would educate about the influence of unsustainable practices (e.g., a mountain of plastic waste) can stimulus conversations and increase awareness. Interactive installations, such as visually striking public displays of waste accumulation, can serve as powerful reminders of the environmental impacts of unsustainable practices (Figure 3). These installations engage passersby emotionally and intellectually, prompting reflection and dialogue within the community.

Figure 3. Interactive public installation illustrating the environmental impact of plastic waste accumulation. Such installations encourage awareness and community engagement toward sustainable practices.

4.8 Street Art

Street art in terms of drawing stencils and hoisting posters conveying messages about sustainability in unexpected locations will surprise the islanders and can be a powerful way to reach a wide audience. Street art, including stenciled messages and posters placed in unexpected locations, has proven to be an effective guerrilla marketing tactic for raising environmental awareness (Figure 4). These artistic interventions attract attention and resonate with both residents and visitors.

Figure 4. Example of street art used as a guerrilla marketing tactic to promote sustainability messages in coastal communities. (Rogers, 2017) Rogers, S. A. (2017, August 7). Messages in the sand: 12 great guerrilla ads at the beach & the river. WebUrbanist. https://weburbanist.com/2017/08/07/messages-in-the-sand-12-great-guerrilla-ads-at-the-beach-river-banks/)

4.9 Community Involvement

To bring the success community involvement is a must. Guerrilla marketing tactics can be used to inspire local shared action, such as organizing community cleanups or promoting local farmers' markets.

4.10 Highlighting Success Stories

Periodical gathering in terms of picnic or any other social gathering showcasing the local initiatives and individual efforts can motivate others to espouse sustainable practices.

4.11 Empowering Local Stakeholders

Local influential stakeholders and influencers can encourage and motivate to adopt the sustainable practices. This effort will be engaging the local communities in the design and implementation of guerrilla campaigns which ultimately can foster a sense of ownership and responsibility.

4.12 Social Media Campaigns

Now a days, social media like Facebook, Instagram and YouTube etc. is dominating to all level's generations, assuredly even within a remote small island. Guerrilla tactics used as such can be augmented through social media, encouraging people to share their experiences and participate in online challenges. By employing these guerrilla tactics, organizations can promote sustainable behaviors in a way that is not only memorable and engaging but also empowers individuals and communities to take action.

5 PROPOSED APPLICATIONS OF GUERRILLA MARKETING IN ISLAND COMMUNITIES

Figure 5 illustrates a framework for designing guerrilla marketing campaigns tailored to island sustainability. Here guerrilla marketing strategies are the independent variables directly influencing the island sustainability by employing different types of guerrilla marketing tactics, which ultimately will create stunning, memorable and positive examples into the hearts and minds of the island inhabitants. The proposed conceptual framework (Figure

5) illustrates how guerrilla marketing strategies can influence sustainable behaviors in island communities. It highlights the relationship between creative interventions and long-term environmental impacts through community participation and awareness.

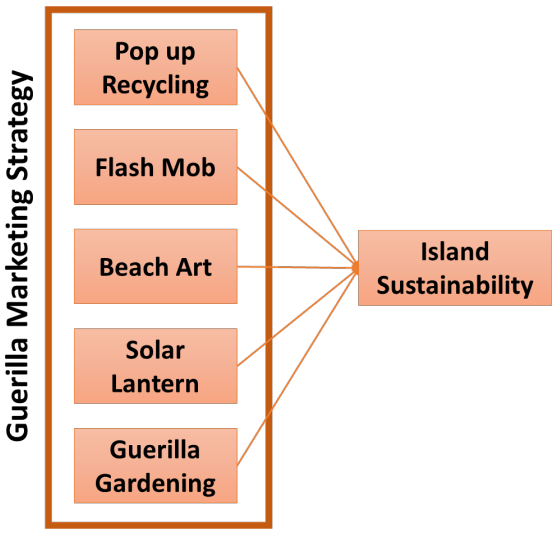

Figure 5. Conceptual Framework Diagram

6 DISCUSSION AND FUTURE DIRECTIONS

The guerrilla marketing strategy appears to be a promising approach for fostering sustainability in island societies, addressing many unprecedented challenges they face due to recurring natural disasters. This low cost and high engagement potential of guerrilla marketing brand it well-suited to all the circumstances where financial and infrastructural resources are insufficient. By promoting local culture, art, and resources, guerrilla marketing campaigns can reverberate intimately with island residents, inspiring positive changes in their behavioral pattern that will definitely bring them into the line with sustainable practices. The examples presented—such as beach art from marine litter, pop-up recycling hubs, and solar lantern festivals—demonstrate that creative, community-driven initiatives can generate visible and lasting environmental benefits.

In comparison with traditional promotional campaign, guerrilla marketing's stress on surprise and unique partaking would certainly help overcome shared pitfalls that belong to traditional campaigns, which often suffer from low engagement or cultural disconnect. At the end, Guerrilla marketing strategies encourage collective responsibility by involving community members directly in the creation and dissemination of messages.

Despite the inherent positive features of guerrilla marketing, there lies some inherent challenges. Evaluating the long-term impact of guerrilla marketing campaigns on environmental behaviors is someway not practicable with their often casual and momentary style. Leveling successful involvements beyond initial pilot areas may also presents logistical and cultural hurdles. Future research should prioritize empirical studies that would evaluate efficacy, ideally through controlled pilot projects in varied island contexts. This would aid recognize best practices, clarify the conditions under which guerrilla marketing excels, and highlight potential limitations.

Guerrilla marketing offers several advantages for promoting sustainability in island communities:

- Affordability: Enables action despite limited budgets.
- High Engagement: Encourages community participation and ownership.
- Cultural Resonance: Leverages local art, traditions, and materials.

Challenges include measuring long-term impact and scaling successful campaigns. Future research should explore empirical studies and pilot projects to test the effectiveness of guerrilla marketing interventions in various island contexts.

7 CONCLUSION

This paper essentially highlights guerrilla marketing as a novel, cost-effective approach to foster sustainable behaviors in island communities. By embracing creativity and community involvement, small actions can ultimately lead to significant positive impacts. Policymakers, NGOs, and local leaders are significant stakeholders exploring guerrilla marketing as a tool for building environmentally resilient island societies. Guerrilla marketing offers an innovative, low-cost, and culturally adaptable approach to endorsing sustainability in island communities facing inimitable environmental challenges. By yoking creativity, local traditions, and community participation, these campaigns can effectively promote awareness and inspire positive change even with inadequate resources.

The examples discussed—from beach art installations to solar lantern festivals—illustrate how trivial, aimed actions can create meaningful and memorable impacts. While traditional environmental campaigns often brawl with cost and engagement, guerrilla marketing's interactive and participatory nature provides a talented alternative that bring into line with the core principles of sustainability: resource conservation, waste reduction, and social empowerment. However, further research and pilot programs are desirable to meticulously assess long-term efficacy and scalability across diverse island settings. Eventually, accepting guerrilla marketing as a instrument for sustainable island living can empower residents, influence visitors, and support policymakers and organizations in building resilient, environmentally cognizant island societies. Small, creative actions have the potential to drive substantial positive changes, protecting fragile island ecosystems and the communities that rely on them for generations.

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Comparative Marketing Decisions among Contact and Non-Contact Smallholder Coffee Growers in Morobe Province, Papua New Guinea

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Abstract: Coffee remains a fundamental component of Papua New Guinea's agricultural economy, generating over K510 million in foreign exchange earnings in the past decade. This study examines the marketing decisions of smallholder coffee growers associated with the Nakama Agribusiness Cooperative in Quepunung village, Morobe Province. By contrasting contact growers (cooperative members) with non-contact growers (independent farmers), the research investigates how personal and socio-economic characteristics influence marketing strategies. Utilizing a sample of 50 growers and employing a mixed-methods approach, the study reveals that, despite demographic similarities between the two groups, contact growers tend to favour rapid sales and bargaining strategies, whereas non-contact growers are more inclined to utilize delay techniques. The findings provide valuable insights for policymakers, cooperatives, and extension services seeking to enhance market participation and income stability for smallholder farmers.

Keywords: Smallholder coffee growers, marketing decisions, cooperatives, agribusiness, socio-economic characteristics

1. INTRODUCTION

Coffee constitutes a fundamental component of Papua New Guinea's agricultural economy, ranking second only to oil palm in terms of export value. With more than 450,000 households involved in coffee cultivation across 18 provinces, the sector serves as a significant source of foreign exchange, generating approximately K510 million over the past decade. Furthermore, it plays a crucial role in supporting rural livelihoods, infrastructure development, and cultural practices (Daviron & Ponte, 2005). Smallholder farmers, who account for over 80% of the country's coffee production, remain pivotal to this industry; however, they encounter ongoing challenges regarding the effective marketing of their produce (Curry et al., 2017b).

This study examines the marketing decisions of smallholder coffee growers in Morobe Province, comparing contact farmers affiliated with the Nakama Agribusiness Cooperative to non-contact farmers in Quepunung village. It investigates how personal and socioeconomic characteristics—such as education, farming experience, and sources of income—influence decision-making in critical areas such as bargaining, delayed sales, and cash exchange. These decisions are influenced by fluctuating prices, logistical costs, and quality control pressures, all of which affect farmers' capacity to benefit from government price support schemes and opportunities in specialty markets.

By analyzing the relationship between farmer profiles and marketing choices, this research seeks to inform targeted interventions aimed at strengthening cooperative participation, enhancing market access, and improving the economic resilience of Papua New Guinea's smallholder coffee sector. The findings are both timely and relevant, providing insights for policymakers, agricultural trainers, and development practitioners who aim to align grassroots realities with national agribusiness strategies.

2. METHODOLOGY

2.1 Study Location and Population

This study was conducted in Boana, located within the Nawaeb District of Morobe Province, Papua New Guinea. The site was selected due to its suitability for both Arabica and Robusta coffee varieties, the high concentration of smallholder coffee farmers, and the presence of both cooperative-affiliated (contact) and conventional (non-contact) growers. Specifically, Ward 12—locally referred to as Quepunung—was chosen for its accessibility and its representation of diverse smallholder farming practices. The region is characterized by a tropical highland climate, with an annual rainfall of approximately 4313 mm.

The study population consisted of 103 smallholder coffee growers, including 47 registered members of the Nakama Agribusiness Cooperative (contact farmers) and 56 non-contact farmers. A total sample of 50 respondents was selected, with an equal distribution between the two groups.

2.2 Sampling Techniques

A mixed sampling approach was employed to ensure both representativeness and feasibility. Purposive sampling was utilized to select contact farmers based on their cooperative membership and production history. Convenience sampling was implemented to address logistical constraints encountered during fieldwork. Simple random sampling was applied to the non-contact farmer group to guarantee unbiased selection. The inclusion criteria mandated that participants possess a minimum of five years of coffee farming experience and have sold coffee within the preceding two years.

Three villages—Drida, Imiks, and Sokam—were selected from Ward 12 due to their proximity and the concentration of coffee growers. Drida functioned as the central hub for data collection activities.

2.3 Research Design

A cross-sectional survey design was employed to gather quantitative data on personal and socioeconomic characteristics, marketing decisions, and their interrelationships. Structured questionnaires were formulated in alignment with the study objectives and were pretested for contextual relevance. The survey design was informed by analogous studies conducted both in Papua New Guinea and internationally, including the works of Ngango and Kim (2019), MacWilliam (2020), and Chingala et al. (2017).

2.4 Data Collection Methods

Primary data were collected through face-to-face interviews utilizing structured questionnaires, which were verbally translated into Tok Pisin to ensure comprehension among respondents. The data encompassed demographic variables (e.g., age, gender, education), farming characteristics (e.g., number of coffee trees, sources of income), and marketing decisions (e.g., bargaining strategies, timing of sales, cash exchange practices) in response to market challenges such as price fluctuations and logistical costs.

To enhance the validity of the findings, naturalistic observations and audio recordings were conducted in conjunction with the survey. These observations documented field practices and marketing behaviors, while the audio recordings enabled respondents to elaborate on closed-ended questions, providing richer qualitative insights.

Secondary data were obtained from published reports and literature regarding the coffee sector in Papua New Guinea, including analyses of marketing trends, challenges faced by farmers, and levels of cooperative participation.

2.5 Data Analysis

Quantitative data was systematically coded and subsequently entered into Microsoft Excel, followed by analysis utilizing SPSS Version 27. Descriptive statistics were employed to summarize demographic and marketing

decision data. Additionally, Pearson correlation analysis was performed to investigate the relationships between personal and socioeconomic characteristics and marketing decisions.

Further analysis of marketing decisions was conducted using the Marketing Decision Index (MDI), which was adapted from Hossain and Miah's (2011) Problem Confrontation Index.
The formula for the MDI is as follows:

$$MDI = (Ab \times 4) + (c \times 3) + (d \times 2) + (E \times 1) \quad (1)$$

Where:

- (Aa) = number of respondents with "very high" decision frequency
- (c) = "high"
- (d) = "medium"
- (E) = "low"

This index quantified the intensity of marketing decisions across different scenarios.

3 RESULTS

The results are presented in three parts which represent the three objectives of this study. The study compared 25 contact and 25 non-contact smallholder coffee growers in Quepunung village.

Part 1: Comparative Personal and Socio-economic Characteristics

Table 1. Comparative Demographic and Educational Profile of Contact and Non-contact Coffee Growers

Variables	Categories	Contact Growers (%)	Non-contact Growers (%) _
Age	Less than 25 years old	32	24
	25 to 40 years old	44	32
	Above 40 years old	24	44
Gender	Male	88	72
	Female	12	28
Education Level	No schooling	4	4
	Primary (Grade 1-8)	60	44
	Secondary (Grade 9 -12)	32	28
	Tertiary and Colleges	4	24

Table 2. Comparative Socio-economic variables of Contact and Non-contact Coffee Growers

Variables	Categories	Contact Growers (%)	Non-contact Growers (%)
Experience	Less than 5 years	8	8
	Between 5 and 20 years	48	24
	More than 20 years	44	68
Tree Count	Less than 100	12	8
	Between 100 and 200	56	40
	More than 200	32	52
Weekly Town Visits	No visit	8	16
	Once per week	44	52
	More than once per week	48	32
Annual Income from Coffee	Less than K1000	28	16
	Between K1000 and K5000	60	48
	Above K5000	12	36

Part 2: Marketing Decisions in Response to Situational Challenges

Marketing decisions—quick sales, bargaining, and delay technique—were analyzed under four common challenges: price fluctuation, logistic costs, quality, and operational costs.

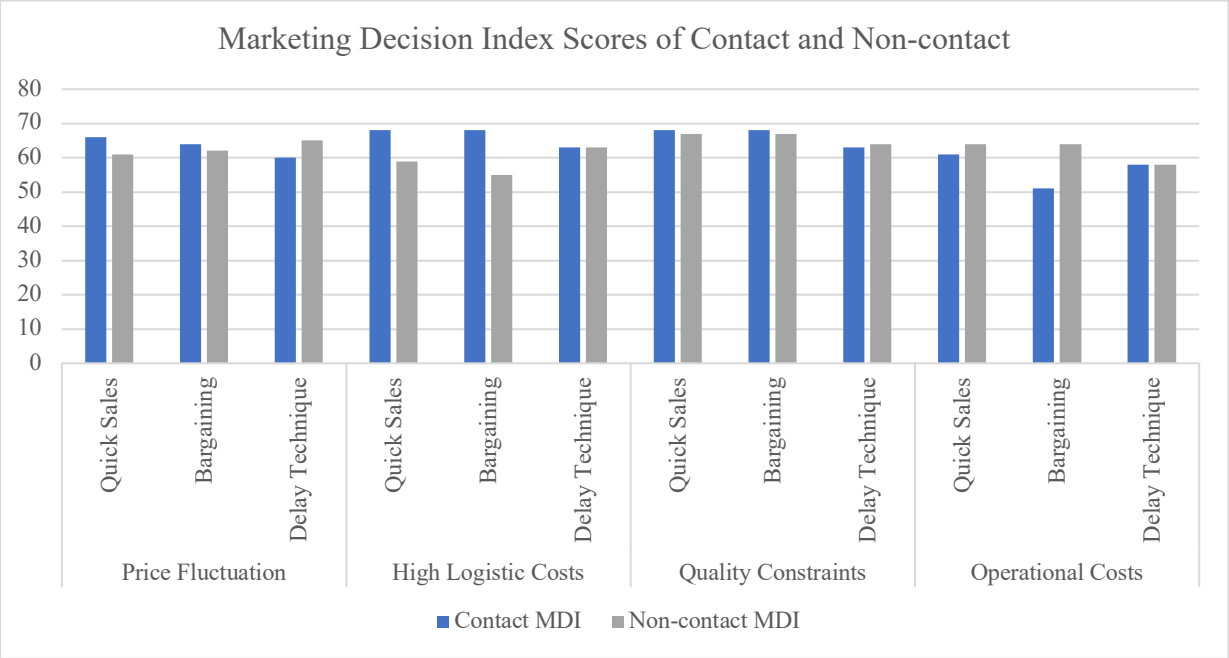

Figure 1: Comparative Marketing Decision Index Scores of Contact and Non-contact Coffee Growers (N=50)

Part 3: Correlation Between Socioeconomic Characteristics and Marketing Decisions

Pearson correlation analysis revealed significant negative relationships between growers' characteristics and their marketing decisions.

Table 3. Correlation Matrix – Contact Growers

Variable	Quick Sales	Bargaining	Delay Technique
Years of Experience	–.722**	–.712**	–.717**
Town Visits	–.804**	–.819**	–.863**
Number of Coffee Trees	–.878**	–.872**	–.806**
Annual Income	–.817**	–.826**	–.873**
Decision Makers	–.725**	–.722**	–.825**

Note: Correlation is significant at the 0.01 level (2-tailed)

Table 4. Correlation Matrix – Non-contact Growers

Years of Experience	–.773**	–.773**	–.791**
Town Visits	–.903**	–.903**	–.823**
Number of Coffee Trees	–.863**	–.863**	–.846**
Annual Income	–.899**	–.899**	–.832**
Decision Makers	–.853**	–.853**	–.890**

Note: Correlation is significant at the 0.01 level (2-tailed)

4 DISCUSSION

This study investigates the personal and socio-economic characteristics of contact and non-contact smallholder coffee growers in Quepunung village, Papua New Guinea, and explores how these characteristics influence their marketing decisions in four critical contexts: price fluctuation, high logistic costs, coffee quality, and operational costs. The comparative analysis reveals nuanced differences in demographic profiles, resource access, and decision-making strategies between the two groups.

Personal Characteristics and Implications

The age distribution of growers indicates that contact farmers were predominantly middle-aged (44%), whereas non-contact growers were more likely to be older (44%) (Table 1). This observation aligns with the findings of Negash (2016), who noted that younger farmers tend to exhibit a greater openness to innovation and certification programs. Despite age disparities, all household members participated in coffee production, underscoring the central role of coffee in rural livelihoods (Bailey, 2009).

Gender disparities were evident, with males predominating in coffee farming within both groups—88% among contact growers and 72% among non-contact growers (Table 1). This trend reflects the patrilineal land ownership structure in Quepunung (Ngeywo et al., 2015) and corroborates the findings of Overfield and Fleming (2001) regarding gendered access to technical knowledge. Female growers encounter obstacles in adapting to new practices due to limited access to extension services and decision-making platforms (Inu, 2015; Eves, 2020).

Educational attainment was modest across both groups, with contact growers showing a higher concentration in primary education (60%) and non-contact growers displaying a slightly greater representation in tertiary education (24%) (Table 1). This suggests that while education is a significant enabler of market adaptation (Wollni & Fischer, 2015), its advancement remains gradual among smallholders in Papua New Guinea (Prior, 2009; Sengere et al., 2019).

Socio-economic Characteristics and Market Engagement

The experience in coffee farming was significantly greater among non-contact growers, with 68% reporting over 20 years of involvement (Table 2). However, this generational knowledge did not necessarily result in proactive market engagement. In contrast, contact growers, although slightly less experienced, demonstrated greater activity in town visits and cooperative activities, indicating stronger market linkages and improved access to information (Fafchamps & Hill, 2005).

Analysis of tree ownership patterns revealed that contact growers managed more compact plots (56% with 100–200 trees), facilitating effective quality control and labor efficiency (Imbun, 2014) (Table 2). Conversely, non-contact growers, who often inherited larger plots, exhibited less consistent attention to tree management, primarily engaging during harvest seasons (Giovannucci & Hunt, 2009).

Income levels were generally moderate, with the majority of growers earning between K1000 and K5000 annually (Table 2). Notably, a higher proportion of non-contact growers (36%) earned above K5000 compared to their contact counterparts (12%), which can be attributed to larger farm sizes and multiple gardens (Lubega & Owino, 2016). However, income alone did not ensure strategic marketing decisions, as evidenced by the correlation analysis.

Marketing Decisions Under Key Situations

In the context of price fluctuations, contact growers preferred rapid sales (MDI 66) and bargaining (MDI 64), utilizing cooperative networks to enhance stability and negotiation power (Newman, 2009; Imbun, 2014). In contrast, non-contact growers tended to adopt delay strategies (MDI 65), awaiting favorable prices but lacking structured support.

High logistical costs presented significant challenges for non-contact growers, who postponed sales due to transport constraints (McKillop, 2010). Supported by the Nakama Agribusiness Cooperative, contact growers

maintained elevated MDI scores for quick sales and bargaining (both 68), reflecting resilience through collective infrastructure (Powae, 2009).

Quality considerations indicated that contact growers prioritized rapid sales and bargaining (MDI 68), which reflects their access to export markets and adherence to quality assurance protocols (Degema & Fleming, 2009). Non-contact growers, lacking such systems, delayed sales due to inconsistent bean quality.

Operational costs elicited divergent responses: non-contact growers favored quick sales and bargaining (MDI 64), motivated by immediate financial needs and limited support. Conversely, contact growers, bolstered by cooperative assistance, opted to delay sales to preserve quality and strategically manage costs (Temu, 1991).

Correlation Between Socio-economic Variables and Marketing Decisions

A strong negative correlation was observed between socio-economic variables and marketing decisions across both groups. For contact growers, increased experience, town visits, tree ownership, and income were correlated with more cautious and selective marketing behaviors. This suggests that informed growers, particularly those embedded within cooperatives, tend to be less reactive and more strategic (Tolera & Gebermedin, 2015; Saragih, 2013).

Despite possessing greater experience and tree ownership, non-contact growers exhibited minimal strategic decision-making. Limited access to market information and cooperative support constrained their ability to respond effectively to market dynamics (Sinaga et al., 2022; Andreatta & Wickliffe, 2002). Their decisions were frequently reactive, driven by immediate needs rather than long-term strategic planning.

5. CONCLUSION

This study investigated the socio-economic characteristics and marketing decisions of contact and non-contact smallholder coffee growers in Quepunung village, Papua New Guinea. The comparative analysis revealed that, while both groups exhibited similar demographic profiles—predominantly male, middle-aged, and possessing primary-level education—distinct differences emerged in their market engagement and decision-making strategies.

Contact growers, frequently associated with the Nakama Agribusiness Cooperative, demonstrated higher Marketing Decision Index (MDI) scores in terms of quick sales and negotiation across various marketing scenarios. Their regular visits to town, support from the cooperative, and access to market information facilitated more strategic responses to price fluctuations, logistical challenges, and quality demands. In contrast, non-contact growers, despite having more experience and larger coffee plots, tended to rely on delay tactics and reactive sales, often hindered by limited access to market networks and extension services.

Statistical analysis confirmed strong negative correlations between marketing decisions and socio-economic variables, including years of experience, number of coffee trees, frequency of town visits, and income levels. These findings suggest that increased experience or resource ownership alone does not ensure improved marketing outcomes without institutional support and market literacy.

The study effectively addressed its core objectives and upheld the null hypothesis, indicating no significant positive relationship between socio-economic characteristics and marketing decisions. Instead, it underscored the nuanced interplay among access, agency, and adaptive capacity in the marketing of smallholder coffee.

6. RECOMMENDATIONS

1. **Expand Cooperative Membership and Support**
   Encourage non-contact growers to register with cooperatives such as Nakama Agribusiness to gain access to structured marketing channels, bargaining platforms, and logistical support. This initiative has the potential to enhance their market reach and stabilize income.

2. **Strengthen Financial Literacy Programs**

Implement targeted financial literacy training for growers to improve skills in budgeting, savings, and income diversification. Such training will empower households to more effectively manage seasonal income fluctuations and make investments in farm improvements.

3. **Enhance Extension Services and Impact Monitoring**
   Develop comprehensive extension service models that incorporate impact tracking systems to evaluate the adoption of marketing strategies and policy changes at the farm level. This approach should encompass both physical outreach and digital engagement tools.

4. **Integrate Climate and Policy Variables in Future Research**
   Broaden the scope of future research to encompass external factors such as climate variability, government regulations, and global market trends. These variables are essential in influencing long-term marketing decisions and farm sustainability.

5. **Promote Inclusive Decision-Making and Gender Equity**
   Support initiatives that encourage shared household decision-making and enhance women's access to technical training and market information. This will contribute to more equitable and efficient farm management practices.

6. **Facilitate Longitudinal Studies on Market Adaptation**
   Conduct longitudinal research to monitor changes in marketing behavior over time, particularly as growers transition between contact and non-contact status. This will yield deeper insights into the evolution of smallholder strategies.

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An analysis of Cultural Intelligence in Different Regions of Papua New Guinea based on Physics Education

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Abstract: Cultural intelligence is important in a globalized world where people from different cultures interact effectively. The cultural factors that influence education in Papua New Guinea are language barriers, traditional knowledge in science, the teaching methods, students' attitude towards science and the societal or family expectations. In our study, we selected physics education because physics is the study of matter and energy which is closely associated with the environment and supports all branches of science, engineering and technology. Cultural quotient has been calculated in different regions of PNG by conducting a survey on first year university physics students from different regions of PNG. Cultural quotient was found to be higher in Highland region and lower in Island region. Remedial methods have been suggested to improve the cultural quotient in all regions of PNG.

Key words: Papua New Guinea, Physics Education, Cultural Intelligence, Language

1. INTRODUCTION

Papua New Guinea is a country in the Pacific that has a population of over 10, 000, 000 with 7,000 different cultures and over 830 distinct native languages. About 20% of the population live in urban centers while 80% of it represents the rural dwellers. The significantly biased population disparity between the urban and the rural inhabitants is geographically dispersed by rugged mountains and ranges. In addition to this, the scabrous geographical landscape of the country has muddy swamps and deadly flowing rivers. The cultural and geographical diversity and linguistic complexity are more specific and unique in the four regions of the country.

Papua New Guinea is divided into four regions called *Southern*, *Islands*, *Momase* and *Highlands*. Each of the four regions have several of both unique and common cultures and languages. Culture plays a significant role in shaping the people's behavior, beliefs, and values in these four regions of the country. Some of the cultural norms are unique to a specific region while others are common to the four regions. For example, traditional dressing and reconciliation are unique but the respect for elders and family values are common in the four regions. One of the key functions of cultural norms is to provide a sense of belonging and identity to individuals within the respective regions. The four regions also embrace the common universal cultural values such as love and justice and the specific one like welcoming strangers into their communities and homes. Cultural values are the key principles or morals that underpin regionalism and culturalism in Papua New Guinea. Local Papua New Guinean students bring regionalism and culturalism into classrooms at all levels of educations system and keep them alive. Kukari (2004) noted that being deeply rooted in their cultural belief systems, both the religious and cultural beliefs influence the way students learn in Papua New Guinea. Hence the efforts to determine the levels of cultural quotient (CQ) in the four regions are highly desirable.

Cultural intelligence (CQ) is the ability to effectively understand, adapt, and work in different cultural contexts. It encompasses four components, including Cognitive CQ, based on knowledge, Metacognitive CQ, based on strategy, Motivational CQ, based on drive and Behavioral CQ, based on action, which help individuals navigate and succeed in culturally diverse environments. According to Ott & Michailova (2016) Cultural Intelligence (CQ), is an individual's capability to function and manage effectively in culturally diverse situations and settings. Experts in cultural intelligence can perform an important function in helping members of different cultural backgrounds to be more effective in multicultural settings. They can also use their skills for effective communication by bridging language barriers and resolving different communication styles. Cultural Intelligence can be used as a tool to mediate the high levels of relationship and process related conflict arising from different cultural misunderstandings. It can also be used to reduce the time that culturally diverse teams take to reach a

conclusion. Dogra & Dixit (2018) stated that 'Cultural Intelligence gives an insight on understanding why some of the individuals are able to cope and succeed in a diverse environment than others' (p. 1). Thomas (2017) found that culturally intelligent people are at a distinct advantage and they are more likely to make correct determinations for the reasons why people who were culturally different behaved as they did.

Cultural intelligence plays a vital role in successful global leadership. It is essential for global leaders to effectively navigate diverse international environments. Understanding global business etiquette is crucial for respecting cultural differences and fostering positive relationships. Leaders with high cultural intelligence are better equipped to lead diverse teams and drive inclusive work environments. Effective cross-cultural engagement strategies enable global leaders to communicate and collaborate seamlessly across cultures. Developing cultural intelligence helps leaders to overcome challenges related to cross-cultural communication. Leadership is the ability and capacity to influence others and is the exercise of authority and making decisions (Bass, 1990).

Choosing physics to understand and embrace the role of cultural intelligence to improve physics education in multicultural classroom settings is vital and necessary. Physics is the multidisciplinary and unifying discipline in the field of natural sciences, engineering and technology. Physics deals with the study of the nature, the basic laws that govern the natural phenomena and the behaviour of matter. The fundamental focus of physics is the study of the relationship between matter and energy which underpins the other areas of study. Matter is composed of elementary particles that interact through fundamental forces.

In physics, there is a wide range of branches such as mechanics, heat, light, sound condensed matter, atomic and molecular physics, elementary particle physics, astrophysics, nanophysics and so on. It is the most difficult science subject having inseparable progressive levels of mathematics with the global trend of declining statistics of students' enrollment. The research in physics includes semiconductor devices that became the heart of the modern technology. Physics concepts are applied to develop and improve infrastructure and services in health, energy, technology, environment, communication, bioscience, space science education, transport, meteorology and entertainment and so on. These sectors play a vital role for sustainable growth of the world. Physics education plays a significant role in educating and training educationists, technical and professional experts who contribute in local, national and global transformation with creative and innovative visions, ideas and skills. Windschitl (2009) "explained that physics education can offer a rich context for developing many 21st-century skills, such as critical thinking, problem solving, and information literacy especially when instruction addresses the nature of science and promotes use of science practices. These skills not only contribute to the development of a well-prepared workforce of the future but also give individuals life skills that help them succeed hence are skills enhance effective leadership skills".

Cultural Quotient (CQ) for physics education is a measure of the subject content and learning environment which align with the students' cultural context and values. It gives the student's familiarity with applications or examples. It depicts how well the teaching methods accommodate with diverse cultural backgrounds. Also, it reflects the students' motivation in learning physics shaped by their cultural experience.

In this paper we calculated the cultural quotient of physics education in the four different regions of Papua New Guinea. We analyzed the cultural intelligence by conducting a survey among the first-year university students taking physics. The data collected was entered into Google Forms as a survey administration software and used the Google Sheets for effective sorting in spreadsheets. We also proposed measures to develop cultural intelligence among students in regions whose cultural quotient scores are low.

Table 1: The number of students who took part in the study from the four regions of Papua New Guinea.

		REGIONS				TOTAL	TOTAL
INSTITUTION		SOUTHERN	MOMASE	HIGHLANDS	ISLANDS		
UPNG	Male	6	15	33	3	57	
	Female	3	12	14	11	40	97
UNITECH	Male	13	10	24	4	51	
	Female	6	12	10	4	32	83
UoG	Male	5	7	28	3	43	
	Female	1	0	4	0	5	48
TOTAL	**Male**	24	32	85	10	**151**	
	Female	10	24	28	15	**77**	**228**
	TOTAL	34	56	113	25	**228**	

The number of students who took part in the study from the four regions of Papua New Guinea is given in Table 1. The survey questionnaire accommodated and explains four different categories. They are 1) learning and understanding physics, 2) aspirations of physics education, 3) influences of English language in learning physics and 4) physics knowledge from the community. The cultural factors that influence physics education in Papua New Guinea are 1) language barrier, 2) interactions of physics concepts with indigenous knowledge, 3) the perception of physics in Papua New Guinea's cultural values and 4) the family or societal expectations that impact the physics education. To calculate CQ, we took some indicators based on 1) understanding the concepts of physics with culturally relevant examples, 2) curriculum flexibility to include local phenomena and availability of teaching and learning resource materials, 3) students' interest, participation and motivation in physics and 4) culturally relevant teaching styles (story telling). To quantitatively evaluate the responses of specific cultural backgrounds, a Likert-scale system is used to measure the student's attitude and engagement in physics education. For measuring qualitative responses related to cultural relevance and engagement, we assigned weightage points based on the depth of the relevant responses (Ang et al., 2007). This is tabulated in Table 2.

Table 2: The assigned weightages for categories 1) Learning and understanding physics, 2) Aspirations of Physics education, 3) Influence of English language in learning Physics and 4) Physics knowledge from the community.

Categories	Indicators	Weightage
1. Learning and understanding physics	There are just too many formulas and equations to remember and understand in physics	1.0
	There are just too many symbols and constants to remember and understand their meanings in physics	1.0
	It was difficult to tell my peer group the problems I had in learning physics in Grades 11 and 12 because physics was just difficult.	1.0
	It was difficult to tell my physics teacher the problems I had in learning physics in Grades 11 and 12 because physics was just difficult.	1.0
	It was difficult for me to participate in Grades 11 and 12 physics classes discussions because physics itself was just difficult.	1.0
	If a student is weak in physics, then that student is also weak in other science subjects	1.0
	If a student is strong in physics, then that student is also strong in other science subjects.	1.0
	I was told by family friends at home that physics was going to be a difficult subject to learn in grades 11 and 12 and that was when I began to get scared of learning physics.	1.0
	I was told by my school friends that physics was going to be a difficult subject to learn in grades 11 and 12 and that was when I began to get scared of learning physics.	1.0
	I was told by my grade 11 physics teacher that physics was going to be a difficult subject to learn and that was when I began to get scared of learning physics.	1.0
2. Aspirations of physics education	Physics is unheard of at primary and high school levels until you reach grade 11	1.5
	Physics is just naturally difficult regardless of how much effort you put in to understand	1.5
	Applying physics in real life experiences is hardly seen or heard of in grades 11 and 12.	1.5
	Future career opportunities in Physics are not common and not popular in grades 11 and 12.	1.5
	Future career opportunities in Physics are not known in grades 11 and 12.	1.5
	I was forced by the education system to take up physics in grade 11	1.5
3. Influences of English language in learning physics	It is not easy to learn physics from other sources apart from the physics teacher	2.0
	The language translation process from mother tongue to motu or tok pisin then to English makes it much more difficult to understand physics.	2.0
	It was difficult for me to share my views on teaching and learning physics in Grades 11 and 12 because it was also difficult for me to use the language and expressions of physics.	2.0
	Because physics was difficult to learn, I would have learnt better if my physics teacher was from the same region as I am.	2.0
4.	I have family members who graduated in physics and other sciences and engineering and that encouraged me to study physics even the subject was challenging.	1.5

	The difficulty of physics was only a challenge. I appreciated learning new techniques, ideas and methods of solving problems and that encouraged me to continue studying physics at university level.	1.5
	In physics I learnt new ideas and things which not many people know and do and this makes me feel proud and unique to continue study physics at university level.	1.5
	Laws of physics are laws of life	1.5

From the score of each indicator, a weighted average of the overall CQ is calculated using the formula

$$CQ = \frac{\Sigma(W_i \times D_i)}{\Sigma W_i} \quad (1)$$

where Wi = weight assigned to each indicator and Di = average score for each indicator.

Similarly, weighted average CQ levels for the four categories for each region were determined using the same formula (Ang et al., 2007).

2. RESULTS & DISCUSSION

Table 3 shows that Highlands Region has the highest weighted average CQ level of 52.27. Momase Region, Southern Region and Islands region have their weighted average CQ levels as 14.75, 14.24 and 9.56 respectively

Table 3: The weighted average of the CQ levels for the four regions under study.

Region	Weighted Average CQ Levels
Southern	14.24
Momase	14.75
Highlands	52.27
Islands	9.56

Fig. 1 shows the significant disparity between the weighted average CQ levels of Highlands Region and the other three regions. This study highlights that culture does influence the way students learn physics in Papua New Guinea with varying levels of CQ across the four regions. This finding aligns with Kukari (2004) who found that classrooms for teaching and learning in Papua New Guinea are polarized by religious and indigenous cultural beliefs.

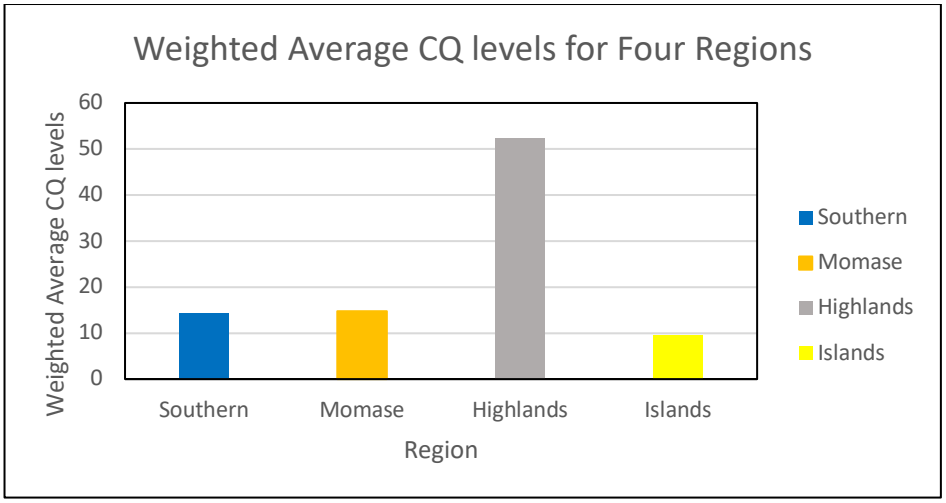

Fig. 1: The weighted average Cultural Quotient levels in the four regions.

Fig. 2 and Table 4 show two significant findings of this study. One is the uniform behaviour of each of the graphs for the four regions. This means that students in Papua New Guinea bring both commonly shared and unique cultural beliefs into their grades 11 and 12 physics classrooms. They also face common challenges and difficulties in learning physics. The impacts of these challenges also vary across the four regions. The other observation is that for all the four regions there is significant increase in the weighted average CQ levels for category four. The Highlands region has the highest weighted average CQ levels for this category compared to the other three regions. This finding highlights the significant impacts of cultural and traditional belief systems, desires, demands and expectations of families, communities and a society as whole upon students learning physics. This study shows how English language affects students learning physics in Papua New Guinea. Language barriers cause fragmentations in physics classrooms in Papua New Guinea when it comes to interpretations, discussions and thought processing of physics concepts. This finding is supported by Morales (2015) who reported that culture and language integration in the teaching and learning processes of physics concepts allow students to develop positive attitude to science, their culture, and native language.

Table 4: The weighted average of the CQ levels for the four categories for the four regions under study.

Categories	Weighted Average CQ Levels			
	Southern	Momase	Highlands	Islands
1	13.7	13.3	51.9	8.8
2	12.2	11.5	42.3	7.2
3	7.5	9.0	32.3	5.0
4	27.3	29.8	94.5	20.5

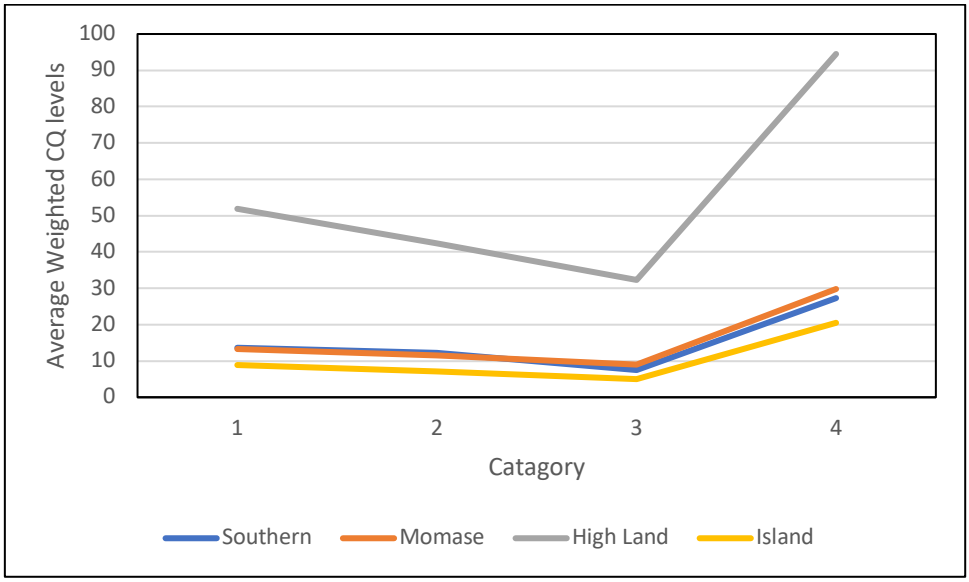

Fig. 2: The weighted average CQ levels based on the four categories

Physics classrooms in Papua New Guinea settings mean more than teaching and learning environment. The dynamics of linguistic and cultural diversity play a significant part in shaping both the teachers' and students' attitudes towards physics. These unseen forces are what both physics teachers and students need to contain to have meaningful and lifelong teaching and learning.
Some of the recommendations to enhance the cultural Intelligence are given below.

- Introduce cultural awareness in schools and universities.

- Conduct cultural competency workshops and training programs in schools and communities.
- Promote cross-cultural interactions like Community events, multicultural festivals and intergroup dialogues that share their customs, food, music and traditions.
- Government and private organizations can organize exchange programs that allow people to travel, live and work in different cultural settings.
- Encourage multicultural programs in media.
- Identify community leaders and empower them to foster empathy and open-mindedness.
- Utilize technology to enhance cultural practices on a global perspective.
- Celebrate diverse cultural programs and encourage reflective practices.

CONCLUSION

CQ levels vary significantly across the four regions of Papua New Guinea. A critical highlight in this study is the weighted average of the CQ levels for the influence of English language in teaching and learning physics in Papua New Guinea. In our study, we observed that average cultural quotient is high in the high land region compared to other regions. In this paper we highlight the remedial measures to improve the CQ levels across the four regions. PNG is known for its cultural diversity with different traditions, customs and life patterns. We recommend to run Physics teacher's upskilling programs to develop and implement appropriate pedagogies for physics teaching and learning in Grades 11 and 12 in multicultural settings. Also, embrace cultural and language integration in physics curriculum to capture local phenomena.

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Solar and Visible-Light Photooxygenations of Furfural – An Example for the Manufacturing of Commodity Chemicals from Renewable Materials

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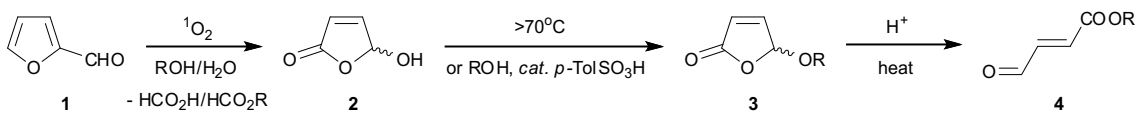
Abstract: This study investigated the photooxygenation of furfural as a bagasse-derived material to the important platform chemical 5-hydroxy-2(5H)-furanone. The reaction was successfully transferred from small laboratory-scales with artificial light to large solar demonstration scales in direct, natural sunlight. Due to the challenging isolation of pure hydroxyfuranone caused by thermal follow-up reactions, pseudo-esterifications and -transesterifications to the corresponding alkoxy-derivatives were furthermore conducted. The results from this investigation offer new opportunities for sugarcane bagasse waste utilization and product diversification of renewable biomass materials.

Keywords: furfural, furanones, photooxygenations, solar chemistry, renewable materials.

1 INTRODUCTION

Due to the growing interest in green and sustainable chemistry, many environmentally conscious methodologies for the synthesis of commodity chemicals from renewable feedstocks have been developed [1-4]. Commodity, fine or platform chemicals can be extracted directly from biomass or can alternatively be derived through chemical conversions of first-generation biomass substrates. Furfural (**1**), for example, is predominantly synthesized from pentose biomass, in particular sugarcane bagasse, via acid-catalysed dehydration [5, 6]. Sugarcane bagasse comprises mainly of cellulose, hemicellulose (pentosan), lignin and ash [7, 8], respectively. This makes bagasse an interesting and readily available resource for value adding and product diversification through chemical modification. While the majority of furfural is further transformed by reduction, its oxidation to 5-hydroxy-2(5H)-furanone (**2**) has recently emerged as an interesting alterative process [9]. Hydroxyfuranone itself represents a versatile C_4-building block in organic synthesis and is accessible through various oxygenation processes from furfural (**1**) [9, 10]. Most of the reported processes and procedures employ inorganic oxidizing agents and solid supported catalysts. These approaches are often challenging to upscale due to hazardous chemicals and wastes. The photooxygenation of furfural (**1**) to hydroxyfuranone (**2**) offers an alternative access instead (**Scheme 1**) [11]. This procedure utilizes short-lived singlet oxygen ($^1O_2$) as an oxidant, which is generated using catalytic amounts of an organic dye and visible light [12].



Scheme 1. Photooxygenation of furfural (**1**) to 5-hydroxyfuranone (**2**) and subsequent conversion to 5-alkoxyfuranones (**3**) and (*E*)-alkyl 4-oxobut-2-enoates (**4**).

Numerous protocols for the photooxygenative transformation of **1** have been described [13-17], and the reaction has also been realized in direct or concentrated sunlight on semi-technical scales [18, 19]. One of the most common follow-up reactions of hydroxyfuranone (**2**) is the conversion to its corresponding alkoxy-derivatives **3** [20-22]. These compounds are commonly found as side-products of the photooxygenation in alcohols or are readily available via pseudo-esterification from hydroxyfuranone (**2**). These alkoxy derivatives have also proven useful as (photo)chemical building blocks, especially for (cyclo)addition reactions [23, 24]. Under acidic conditions, thermal ring-opening and isomerization furthermore generates the corresponding (*E*)-alkyl 4-oxobut-2-enoates (**4**) [25]. Due to the chemical and synthetic versatility of both, hydroxy (**2**) and alkoxyfuranones (**3**), this study further investigated the photooxygenation of furfural (**1**) and subsequent pseudo-(trans)esterification as efficient and sustainable pathways to these important building blocks. The photochemical approach utilized different experimental setups and light sources, while the thermal conversions evaluated various sources of starting materials.

2 MATERIALS AND METHODS

2.1 General Information

Technical grade furan-2-carbaldehyde (furfural, **1**) was purified by fractional distillation at normal pressure. The pale-yellow fraction formed at 161°C was collected and its purity confirmed by GC-analysis. All other reagents and solvents were purchased from Merck Life Science Pty Ltd. (Bayswater, VIC, Australia) or Thermo Fisher Scientific Australia Pty Ltd. (Scoresby, VIC, Australia) and were used as supplied.

Melting points were measured in open capillaries using a Tathastu or Gallenkamp melting point apparatus and are uncorrected.

NMR spectra were recorded on a Bruker 400 AscendTM (^{1}H: 400 MHz and ^{13}C: 100 MHz) equipped with an auto-sampler. Data and spectra were processed using the MestReNova software (Version 6.0.2-5475, Mestrelab Research S.L., Santiago de Compostela, Spain). Samples were prepared in $CDCl_3$ (δ = 7.26/77.3 ppm), and the residual solvent peak was used as a reference [26].

Mass spectra were obtained on a Shimadzu LCMS-2020 equipped with a DUIS ion source. Samples were directly injected, and the ions generated were detected in positive, negative or both modes (mass range: 100-500 m/z). The mobile phase consisted of an aqueous solution of 0.1% formic acid in HPLC grade methanol. Experimentation and data processing were done using the LabSolutions for LCMS-2020 software.

Infrared analysis was conducted on an IR-ATR iD5 (Thermo Scientific) spectrometer. Signals were scanned over a range of 500-4000 cm^{-1}.

UV-Vis spectra were recorded on a Cary 60 UV-Vis Spectrometer (Agilent Technologies). Signals were scanned within the 200-800 nm range. Spectra and λ_{max} of characteristic peaks were processed using the CaryWin UV60 software (Varian).

TLC chromatography was performed on 20 cm × 20 cm × 0.2 mm plastic sheets coated with silica gel 60 F_{254} (0.2 mm thickness; Merck, Germany). Mixtures of ethyl acetate and *n*-hexane were used as mobile phases. Visualization was achieved by UV-analysis or by dipping into a potassium permanganate solution.

Flash chromatography was performed using the CombiFlash Lumen (Teledyn ISCO, USA) instrument with an adjustable 32-65 g or 15-25 g solid load cartridge. The cartridges were packed with 50-60 g or 15-21 g of silica gel 60 depending on their sizes. Elutions were carried out using gradients of ethyl acetate in *n*-hexane at a flow rate of 35 $ml.min^{-1}$. Peaks were detected by UV-Vis analysis at 254 nm and 280 nm, respectively, or evaporative light scattering (ELS) at 30°C. Active fractions were auto collected, evaporated and dried.

Small-scale batch reactions were conducted in a Rayonet RPR-200 photochemical chamber reactor (Southern New England Ultraviolet Company, USA) equipped with 16 × 8 W cool-white fluorescent tubes (TL Mini 8W/33-640 1PP/10, Phillips-Signify, The Netherlands) (**Figure 1a**). Reactions were carried out in Pyrex Schlenk vessels of 75pprox.. 100-150 ml capacity. Oxygen was fed through a narrow side arm attached to a sintered glass frit on the bottom of the flask. A cold finger with circulating chilled water was inserted into the vessel to cool the reacting solution during irradiation.

Larger scale irradiations were conducted in an immersion well reactor from an unknown manufacturer (**Figure 1b**). The reactor had a capacity of 250 ml and was made from Pyrex glass. A 150 W medium-pressure mercury lamp (TQ-150, Heraeus Nobelelight, Germany) was inserted into the reactor. Through the narrow glass tube alongside the flask, an FEP tube was passed with a porous metal filter attached at its end for oxygen supply. The reaction mixture was magnetically stirred during operation. Chilled water was circulated through the immersion well to cool the reacting solution and lamp. The entire setup was placed in a wooden box to protect from UV-rays. Solar illuminations were performed in a custom-made flatbed reactor by Wexford Viking Glass Ltd in Ireland (**Figure 1c**). The reactor consisted of a rectangular box (35 × 98 cm or 3430 cm^2 exposed aperture) with an outer thickness of 3 cm and a 10 L capacity. It was fabricated from thick Pyrex glass in an aluminium frame and was covered with a reflective aluminium film on its back. The flatbed reactor was placed on a tilted steel frame angled at 76pprox.. 17°. Teflon tubing was used to connect the reactor to the adjacent colling loop. The lower outlet was linked to a rotary pump (Type 2-MD-SC, Little Giant, USA), which pumped the reaction mixture against gravity through a large intensive-condenser cooled with tap water. The solution was fed back into the flatbed through an opening at its top. Air was supplied at 15 LPM via a stainless-steel gas inlet tube at the bottom of the reactor. An air pump with a flow meter was connected to the gas inlet valve via PVC tubing. The temperature of the flatbed chamber was monitored with a mercury thermometer, which was inserted through an opening at the top of the flatbed and kept submerged throughout operation. The reactor loop was kept in a stainless-steel tray, which was also used to roughly orient the entire solar loop towards the sun. All solar experiments were carried out in either December 2019, May 2020 or November 2020 outside the Molecular Genetics Building on the James Cook University campus (latitude 19°19’50” S and longitude 146°45’33” E) in Townsville, Australia. UV radiation indices were collected from the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

(a) (b) ©

Figures 1. (a) Schlenk flask inside a Rayonet chamber reactor. (b) Immersion well reactor. (c) Solar flatbed reactor.

2.2 Experimental Procedures

2.2.1 Small-scale Irradiations in the Rayonet Reactor

A solution of 3.2-9.7 g (2.8-8.4 ml, 33-101 mmol) of distilled furfural, 100 ml of technical ethanol (96%) and 55-147 mg of rose bengal was transferred to a Schlenk flask. A cold finger was inserted, and the gas feeding tube was connected to the oxygen supply. Once a gentle and stable gas supply was achieved, the Rayonet reactor was turned on. During the reaction, any evaporated solvent was refilled regularly. At the end of the irradiation, the gas supply was stopped and disconnected, the reaction mixture was poured into a round bottom flask, and the reactor was rinsed with approx. 50 ml of technical ethanol. The combined ethanolic solutions were subsequently evaporated at <30°C and ≤100 mbar. The crude oily residue obtained was dissolved in little dichloromethane. To this dark red solution, liquid nitrogen was added in small portions until crystals started to form. The crystals were collected by filtration on a Büchner funnel, washed with cold dichloromethane and air dried. Alternatively, crystallization was facilitated by seeding with small amounts of pure hydroxyfuranone crystals followed by refrigeration overnight.

2.2.2 Laboratory-scale Irradiations in the Immersion-well Reactor

28.6-29.9 g (24.7-25.8 ml, 298-311 mmol) of distilled furfural and 650-786 mg of rose bengal were dissolved in 250 ml of methanol and transferred to an immersion well reactor. The gas feeding was adjusted to a gentle purging, magnetic stirring was started, and the lamp was ignited. During operation, any evaporated methanol was refilled and of bleached rose bengal (0.5 g portions) was refed in regular intervals. At the end of the irradiation, the oxygen supply was stopped, the reaction mixture was transferred to a round bottom flask, and the reactor vessel was thoroughly rinsed with approx. 50 ml of methanol. The combined methanolic phases were subsequently evaporated at <30°C and ≤100 mbar. The product was isolated from the oily residue as described above under 2.2.1.

2.2.3 Demonstration-scale Illuminations in the Flatbed Reactor

A 500 ml flask wrapped with aluminium foil was filled with 247-282 g (213-243 ml, 2.57-2.94 mol) of distilled furfural and 100 ml of technical or absolute ethanol. To this solution, 5.3-10.4 g of rose bengal were added in portions upon swirling until a homogeneous solution was obtained. The solar flatbed was directed towards the sun and the cooling water to the external condenser was started. Then 6.8-7.9 l of technical or absolute ethanol were filled into the reactor through the top opening, and the reactor was covered with light-tight black cloth. The furfural-rose bengal stock solution was subsequently added through the top opening, followed by 100 ml of wash ethanol used for rinsing of the stock vessel. The air pump was switched on, the gas feeding valve was opened, a gentle air stream through the solution was adjusted, and the circulation pump was switched on. Once a stable flow was achieved, the black cloth was removed, and the system was exposed to sunlight. Approximately every 30 minutes, the reactor was repositioned towards the direction of the sun. Additional portions of rose bengal (1 g) and ethanol (100-200 ml) were occasionally added to compensate for photobleaching and evaporation losses, respectively. During interruptions overnight, the gas feeding line was closed, the air and circulation pumps were stopped, the cooling water was turned off, and the reactor was covered with dark cloth. Reactions were restarted the following day as described above. At the end of the illumination, the reactor was covered again with the light-tight cloth, and the reaction mixture and additional ca. 250 ml of wash ethanol were emptied into three amber 2.5 L Winchester bottles. Approximately 500 ml portions of the crude reaction mixture were successively evaporated at <30°C and ≤100 mbar. The product was subsequently isolated as described above under 2.2.1.

2.2.4 Synthesis of Alkoxyfuranones by Pseudo-Esterification

A mixture of 2.02-9.35 g (20.2-93.4 mmol) of hydroxyfuranone, 0.5 g (2.63 mmol) of *para*-toluenesulfonic acid monohydrate, alcohol (ca. 1.1 mol-equivalent) and 150 ml of chloroform was refluxed on a Dean-Stark setup. Once no more water was formed (after approx. 5-6 hours), the reaction mixture was cooled to room temperature, carefully washed with aqueous $NaHCO_3$-solution and brine, dried over anhydrous Na_2SO_4, and concentrated to dryness at <50°C and ≤100 mbar. The desired alkoxyfuranones were subsequent isolated by vacuum distillation or flash chromatography.

2.2.5 Synthesis of Alkoxyfuranones by Pseudo-Transesterification

A solution of 10.2-25.6 g (79.6-200.2 mmol) of ethoxyfuranone, 0.5 g (2.63 mmol) of *para*-toluenesulfonic acid monohydrate, alcohol (ca. 1.1 mol-equivalent) and 150 ml of chloroform was refluxed on a Dean-Stark setup for 15 hours. The reaction mixture was treated as described above under 2.2.4. The desired alkoxyfuranones were subsequent isolated by flash chromatography.

2.3 Spectroscopic details

All compounds isolated were identified by NMR-spectroscopy, and their spectroscopic details matched previously described data [14, 17, 20, 27-30].

5-Hydroxyfuran-2(5H)-one (**2**) [14, 17]. Colourless solid. M.p.: 54-56°C (Lit.: 52°C [14]). ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.29 (dd, *J* = 5.6, 1.2 Hz, 1H, =CH), 6.23 (dd, *J* = 5.6, 1.1 Hz, 1H, =CH), 6.21 (dd, *J* = 1.2, 1.1 Hz, 1H, C<u>H</u>OH), 4.21 (br. s, 1H, OH). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 171.6 (s, 1C, C=O), 152.2 (d,

1C, CHOH), 124.8 (d, 1C, =CH), 99.0 (d, 1C, =CH). ESI-MS: *m/z* = 99 ([M-H]$^-$, 96%), 100 ([M+H]$^+$, 4%), 199 ([2M-H]$^-$, 92%), 200 ([2M]$^+$, 8%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 3250, 1719, 1911, 1275, 1127, 704.

5-Methoxyfuran-2(5H)-one (**3a**) [27]. Yellowish liquid. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.21 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 6.25 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 5.86 (dd, *J* = 1.2 Hz, 1H, CHO), 3.58 (s, 3H, OCH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 170.5, (s, 1C, C=O), 150.1 (d, 1C, =CH), 125.4 (d, 1C, =CH), 104.2 (d, 1C, CHOMe), 57.2 (q, 1C, OCH_3). ESI-MS: *m/z* = 115 ([M+H]$^+$, 100%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 2939, 1761, 1472, 1128, 990.

5-Ethoxyfuran-2(5H)-one (**3b**) [28]. Yellowish liquid. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.20 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 6.21 (dd, *J* = 5.7, 1.3 Hz, 1H, =CH), 5.92 (dd, *J* = 1.3, 1.2 Hz, 1H, CHOEt), 3.92 (dq, *J* = 9.4, 7.1 Hz, 1H, OCH_2), 3.75 (dq, *J* = 9.4, 7.1 Hz, 1H, OCH_2), 1.27 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 170.6 (s, 1C, C=O), 150.5 (d, 1C, =CH), 125.1 (d, 1C, =CH), 103.3 (d, 1C, CHOEt), 66.3 (t, 1C, OCH_2), 15.1 (q, 1C, CH_3). ESI-MS: *m/z* = 129 ([M+H]$^+$, 100%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 2981, 1756, 1349, 1116, 1007, 890, 699.

5-Isopropoxyfuran-2(5H)-one (**3c**) [29]. Yellowish liquid. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.17 (dd, *J* = 5.7, 1.0 Hz, 1H, =CH), 6.19 (dd, *J* = 5.7, 1.1 Hz, 1H, =CH), 5.99 (dd, *J* = 1.2, 1.1 Hz, 1H, CHO^{i}Pr), 4.09 (m, 1H, OCH), 1.26 (t, *J* = 7.1 Hz, 6H, 2 × CH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 170.9 (s, 1C, C=O), 150.9 (d, 1C, =CH), 124.8 (d, 1C, =CH), 102.2 (d, 1C, CHO^{i}Pr), 73.7 (d, 1C, OCH), 23.3 (q, 1C, CH_3), 22.1 (q, 1C, CH_3). ESI-MS: *m/z* = 157 ([M+CH_3]$^+$, 100%), 159 ([M+OH]$^-$, 31%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 2976, 1755, 1383, 1112, 1009, 891, 684.

5-Butoxyfuran-2(5H)-one (**3e**) [20]. Yellowish liquid. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.20 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 6.22 (dd, *J* = 5.7, 1.3 Hz, 1H, =CH), 5.92 (dd, *J* = 1.3, 1.2 Hz, 1H, CHO^{n}Bu), 3.87 (dt, *J* = 9.3, 6.6 Hz, 1H, OCH_2), 3.68 (dt, *J* = 9.3, 6.6 Hz, 1H$_g$), 1.61 (m, 2H, CH_2), 1.39 (m, 2H, CH_2), 0.92 (t, *J* = 7.4 Hz, 3H, CH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 170.7 (s, 1C, C=O), 150.5 (d, 1C, =CH), 125.2 (d, 1C, =CH), 103.5 (d, 1C, CHO^{n}Bu), 70.5 (t, 1C, OCH_2), 31.6 (t, 1C, CH_2), 19.2 (t, 1C, CH_2), 13.9 (q, 1C, CH_3). ESI-MS: *m/z* = 157 ([M+H]$^+$, 100%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 2955, 1757, 1463, 1123, 1016, 890, 685.

5-Hexyloxyfuran-2(5H)-one (**3f**) [30]. Yellowish liquid. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.20 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 6.22 (dd, *J* = 5.7, 1.3 Hz, 1H, =CH), 5.91 (dd, *J* = 1.3, 1.2 Hz, 1H, CHO^{n}Hex), 3.85 (dt, *J* = 9.3, 6.7 Hz, 1H, OCH_2), 3.76 (m, 1H, OCH_2), 1.70-1.53 (m, 4H, 2 × CH_2), 1.37-1.20 (m, 4H, 2 × CH_2), 0.88 (t, *J* = 6.9 Hz, 3H, CH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 170.7 (s, 1C, C=O), 150.5 (d, 1C, =CH), 125.1 (d, 1C, =CH), 103.5 (d, 1C, CHO^{n}Hex), 70.8 (t, 1C, OCH_2), 31.6 (t, 1C, CH_2), 29.6 (t, 1C, CH_2), 25.7 (t, 1C, CH_2), 22.7 (t, 1C, CH_2), 14.1 (q, 1C, CH_3). ESI-MS: *m/z* = 185 ([M+H]$^+$, 100%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 2930, 1759, 1467, 1125, 1079, 890, 686.

5-Cyclohexyloxyfuran-2(5H)-one (**3g**) [29]. Yellowish oil. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.18 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 6.20 (dd, *J* = 5.7, 1.3 Hz, 1H, =CH), 6.04 (dd, *J* = 1.3, 1.2 Hz, 1H, CHO^{c}Hex), 3.78 (ddd, *J* = 13.3, 8.6, 3.9 Hz, 1H, OCH),1.99-1.93 (m, 2H, CH_2), 1.76-1.72 (m, 2H, CH_2), 1.58-1.53 (m, 2H, CH_2). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 170.9 (s, 1C, C=O), 150.9 (d, 1C, =CH), 124.9 (d, 1C, =CH), 102.1 (d, 1H, CHO^{c}Hex), 79.3 (d, 1C, OCH), 33.3 (t, 1C, CH_2), 32.1 (t, 1C, CH_2), 25.5 (d, 2C, 2 × CH_2), 24.1 (d, 1C, CH_2). ESI-MS: *m/z* = 183 ([M+H]$^+$, 100%). IR (ATR): $\tilde{\nu}$ (cm^{-1}) = 2955, 1757, 1437, 1133, 1076, 991, 684.

5-Dodecyloxyfuran-2(5H)-one (**3h**) [30]. Colourless oil. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.44 (dd, *J* = 5.7, 1.2 Hz, 1H, =CH), 6.27 (dd, *J* = 5.7, 1.3 Hz, 1H, =CH), 6.07 (dd, *J* = 1.3, 1.2 Hz, 1H, CHODodec), 3.81 (dt, *J* = 9.5, 6.6 Hz, 1H, OCH_2), 3.71 (dt, *J* = 9.5, 6.6 Hz, 1H, OCH_2), 1.62 (m, 2H, CH_2), 1.40-1.23 (m, 18H, 9 × CH_2), 0.88 (t, *J* = 6.9 Hz, 3H, CH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 165.1 (s, 1C, C=O), 140.4 (d, 1C, =CH), 125.2 (d, 1C, =CH), 103.5 (d, 1C, CHODodec), 70.8 (t, 1C, OCH_2), 66.1 (t, 1C, CH_2), 32.1 (t, 1C, CH_2), 29.8 (t, 2C, 2 × CH_2), 29.5 (t, 2C, 2 × CH_2), 28.6 (t, 1C, CH_2), 26.0 (t, 1C, CH_2), 22.8 (t, 1C, CH_2), 14.3 (q, 1C, CH_3). ESI-MS: *m/z* = 269 ([M+H]$^+$, 100%), 267 ([M-H]$^-$, 5%).

(*E*)-Ethyl 4-oxobut-2-enoate (**4b**). In mixture with **3b**. ^{1}H-NMR (400 MHz, $CDCl_3$): δ (ppm) = 9.76 (d, *J* = 7.6 Hz, 1H, CHO), 6.97 (dd, *J* = 15.9, 7.6 Hz, 1H, =CH), 6.72 (d, *J* = 15.9 Hz, 1H, =CH), 4.30 (q, *J* = 7.1 Hz, 2H, OCH_2), 1.34 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C-NMR (100 MHz, $CDCl_3$): δ (ppm) = 192.6 (d, 1C, CHO), 165.0 (s, 1C, C=O), 140.5 (d, 1C, =CH), 139.5 (d, 1C, =CH), 61.9 (t, 1C, OCH_2), 14.2 (q, 1C, CH_3).

3 RESULTS AND DISCUSSIONS

3.1 Photooxygenation Experiments

Several protocols for the photooxygenation of furfural (**1**) have been reported [13-17, 19]. The initial irradiation procedure patented by Schenck used ethanol as a solvent and solely produced ethoxyfuranone (**3b**) [31]. A later study revealed that hydroxyfuranone (**2**) can be isolated if the temperature is kept below 70°C during the reaction and subsequent isolation [32]. Hydroxyfuranone (**2**) is known to crystallize at low temperatures (<0°C), but only when in a sufficient purity to achieve supersaturation. Due to this difficult and demanding crystallization, crude **2** is typically used for further transformations without purification [14].

3.1.1 Small-scale Irradiations in the Rayonet Reactor

A series of photooxygenation experiments was initially conducted in the Rayonet laboratory reactor (**Figure 1a**) using modified procedures reported by Hui and co-workers [16], Esser et al. [19] and Schenck [31], respectively. Rose bengal disodium salt was chosen as common sensitizer due to its favourable singlet oxygen generation efficiency [33]. Likewise, ethanol (technical grade, 96%) was selected as solvent due to its low toxicity and excellent solvation ability [34]. Solutions of freshly distilled furfural (**1**) were irradiated at 21°C using different loadings of reagent and sensitizer (**Scheme 1**). During each reaction, the distinctive bright red colour of rose bengal notably faded to reddish orange, especially for lower sensitizer and higher furfural concentrations. At the end of each photooxygenation experiment, the solution was carefully evaporated at <30°C to minimize undesired thermal conversions, and the crude reaction mixture was analysed by ^{1}H-NMR spectroscopy to determine its composition (**Table 1**). Pure hydroxyfuranone (**2**) was subsequently isolated by freeze crystallization. A common issue was the persistence of residual rose bengal or coloured impurities in the crystal lattice of the isolated product, thus demanding repeated decolourization treatments.

Table 1. Experimental parameters and results for irradiations in the Rayonet reactor (100 ml of 96% EtOH, 21°C).

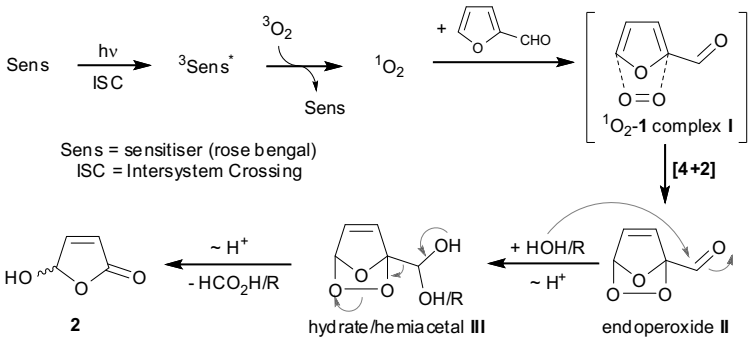
Entry	Loadings		Time	Composition of crude product[a]				Yield of 2
	1 (g/mM)	RB[b] (mg/mol%)	(hrs)	1 (%)	2 (%)	3b (%)	4b (%)	(%)[c]
1	5.8/575	55/0.09	9	1	94	4	1	36
2	9.7/929	147/0.14	20	4	87	8	1	47
3	5.5/546	78/0.13	20	—	73	22	5	30
4	3.2/325	84/0.25	20	—	98	1	1	33
5[d]	3.2/325	85/0.25	1	—	98	1	1	33
6	3.2/325	86/0.26	7	—	99	1	—	46
7	9.7/929	142/0.14	2	—	100	—	—	52

[a] Determined by ^{1}H-NMR (±2%). [b] RB = rose bengal disodium salt. [c] Isolated yield after crystallization. [d] Samples (ca. 1 ml) taken every 10 minutes.

Under all irradiation conditions, excellent to complete consumptions of **1** were observed, although irradiation times varied widely from 1-20 hours. The desired hydroxyfuranone (**2**) was detected as the main to sole component with 73-100% in the crude reaction mixture. However, significant material losses and hence reduced recovery rates of **2** were caused by repeated recrystallization [35]. As a result, the desired product **2** was isolated in varying yields of 30-52%. Exhaustive reaction times somewhat favoured the formation of the ethoxy-derivative **3b** (**Table 1**, Entries 2 and 3), while the amounts of (*E*)-ethyl 4-oxobut-2-enoate (**4b**) remained generally low. Naturally, the best isolated yield of 52% was achieved when hydroxyfuranone (**2**) was formed as the sole product (**Table 1**, Entry 7).

According to the generally accepted reaction mechanism (**Scheme 2**) [25], singlet oxygen initially forms a complex with furfural (**I**), which completes the [4+2]-cycloaddition to the endoperoxide intermediate **II**.

Nucleophilic attack by either water or alcohol at the exposed carbonyl group generates an unstable hydrate or hemiacetal intermediate (**III**), which subsequently collapse to hydroxyfuranone (**2**). Formic acid or its alkyl-ester are formed as additional decomposition products. As water is significantly more nucleophilic than alcohol, the presence of water is beneficial for the formation of **1**. Consecutive photooxidation of formic acid to carbon dioxide and water has also been suggested, hence explaining the formation of **2** under anhydrous conditions [36].



Scheme 2. Mechanism of the photooxygenation of furfural (**1**) to 5-hydroxyfuranone (**2**).

The generation and accumulation of formic acid likely catalysed pseudo-esterification of hydroxyfuranone (**2**) to its ethoxy-derivative **3b** during prolonged reaction and elevated temperatures [31, 32]. To investigate this, a solution of **2** (30 mg) in 9 ml of methanol and 0.5 ml of formic acid was heated to 70°C for 4 hours. After careful neutralisation and extraction, NMR analysis of the crude product confirmed complete conversion into methoxyfuranone (**3a**). Subsequent micro-vacuum distillation furnished pure **3a** in a yield of 60%. This experiment thus unambiguously confirms that pseudo-esterification can unintentionally occur during the photooxygenation process or its isolation and purification stages. Heat management is thus crucial to obtain hydroxyfuranone (**2**) in sufficient quantities and purity.

To monitor the progress of the irradiation, samples from Entry 5 with the lowest concentration of **1** were taken every 10 minutes and were subsequently analysed by ^{1}H-NMR (**Figure 2**). The conversion of furfural (**1**) quickly reached approx. 80% within the first 10 minutes and near completion after just 40 minutes, respectively. The amounts of the ethoxylated side-products **3b** and **4b** fluctuated slightly during the experiment, possibly due to their unintended formation during evaporation and storage. Bleaching of the sensitizer was noticeable and may have retarded the reaction at higher conversions.

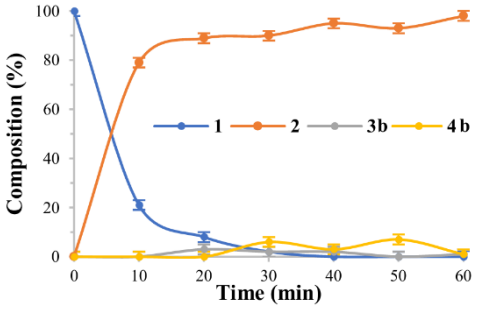


Figure 2. Composition over time profile (Entry 5).

Sensitizer bleaching is commonly observed during photooxygenations [37], especially for large scale operations that demand extended irradiation times. Thus, a solution of rose bengal (57 mg) in technical ethanol (100 ml) was irradiated for 5 hours in the Rayonet reactor while being purged with oxygen. At the end of the reaction, the λ_{max} absorbance of the solution at 558 nm had dropped by almost 50%, clearly demonstrating the extend of bleaching. Photooxygenations of furfural are mainly conducted in either methanol or ethanol [13-17, 19]. Although photoreactions in these alcohols generally proceed fast and efficiently, they easily produce larger amounts of the methoxylated or ethoxylated compounds **3a,b** and **4a,b** through thermal follow-up reactions. Hence, additional photooxygenation experiments were conducted with diluted solutions of **1** in ethanol, isopropanol and *tert*-amyl alcohol, respectively. The later alcohols were investigated as potentially less reactive solvents for consecutive

pseudo-esterifications. To assist with the solvation of rose bengal and breakdown of the endoperoxide intermediate **II** (**Scheme 2**), 4 vol-% of water were added and the solutions were extensively sonicated prior to light exposure. Despite this treatment, the *tert*-amyl alcohol solution remained partially turbid. After irradiation for 10 hours, the compositions of the carefully evaporated and dried reaction mixtures were analysed by ^{1}H-NMR (**Table 2**). An isolation of **2** was not attempted for these reactions.

Table 2. Experimental parameters and results for solvent screening (100 ml, 10 hrs, 21°C).

Entry	Loadings		ROH[a]	Composition of crude product[b]			
	1 (g/mM)	RB[c] (mg/mol%)		1 (%)	2 (%)	3 (%)	4b (%)
8	2.1/215	22.3/0.10	EtOH	—	74	24 (**3b**)	2 (**4b**)
9	2.1/215	22.1/0.10	^{i}PrOH	8	86	3 (**3c**)	3 (**4c**)
10	2.0/205	21.0/0.10	^{t}AmOH	21	69	— (**3d**)	10 (**4d**)

[a] 4 Vol-% of water. [b] Determined by ^{1}H-NMR (±2%). [c] RB = rose bengal disodium salt.

Under almost identical irradiation conditions, the selection of alcoholic solvent impacted significantly on the conversion rates and hence product compositions. As with previous experiments, irradiation in ethanolic solution achieved complete consumption, but produced a mixture of the desired hydroxyfuranone (**2**) and its thermal follow-up products **3b** and **4b** (Entry 8). The photooxygenation conducted in isopropanol showed a near complete conversion of 92% with a favourable selectivity towards **2** and only minor amounts of the corresponding alkoxy-derivatives **3b** and **4b** of 3% each (Entry 9). In contrast, 21% of unreacted **1** remained in *tert*-amyl alcohol as the solvent, with 10% of (*E*)-*tert*-pentyl 4-oxobut-2-enoate (**4d**) as the only detectable side-product (Entry 10).

The choice of solvent significantly changes the optical and physicochemical properties of the solution. In particular, polarities, light transmittances and oxygen solubilities decrease in the order of EtOH > ^{i}PrOH > ^{t}AmOH [38], thus effecting the efficiency of the photooxygenation. The decreasing polarity also reduces the solubility of rose bengal and produces less transparent solutions with hindered light penetration. Similarly, the decrease in nucleophilicity of the alcohols due to increasing steric hinderance of their alkyl groups minimizes pseudo-esterifications [39, 40], hence improving selectivity. In contrast, rising boiling points necessitate harsher evaporation conditions, especially for *tert*-amyl alcohol (B.p.: 101°C), thus favouring further thermal transformations. The results from the solvent study generally align with these interpretations as the reaction conducted in ethanol gave the highest conversion but showed the lowest selectivity (Entry 8). In contrast, the usage of *tert*-amyl alcohol furnished the lowest conversion and solely produced **4d** as a side-product instead (Entry 10). Similarly, incomplete reactions and large amounts of thermal by-products have also been described for photooxygenations of **1** in *n*-butanol at 60°C [41].

3.1.2 Laboratory-scale Irradiations in the Immersion-well Reactor

To obtain multigram quantities of the desired hydroxyfuranone (**2**), the photooxygenation was furthermore conducted in a larger laboratory-scale immersion well reactor equipped with a more powerful 150 W medium-pressure mercury lamp (**Figure 1b**) [38, 42]. Adapting the reaction protocol developed by Moradai et al. [14], solutions of **1** and rose bengal in methanol were irradiated while being purged with a gentle stream of oxygen gas (**Scheme 1**). Despite the more powerful light source, the reaction temperature remained constant at 21°C during irradiation. However, the harsher UV-conditions caused severe bleaching of the photosensitiser rose bengal for all reactions [33, 43, 44], and the colour of the reaction mixtures generally changed from bright, transparent and red to fluorescent, turbid and orange. Additional feeding of fresh sensitizer material was thus required to improve subsequent conversions. After careful evaporation, the composition of each crude product was analysed by ^{1}H-NMR and product **2** was then isolated by crystallization (**Table 3**). Initially, all photooxygenation experiments readily consumed furfural (**1**) as notifiable from TLC monitoring. However, increasing sensitizer bleaching significantly retarded the progress of the reaction and hence demanded exhaustive irradiation times of 19-36 hours to reach near or complete consumptions.

Table 3. Experimental parameters and results for irradiations in the Immersion-well reactor (250 ml of MeOH, 21°C).

Entry	Loadings		Time	Composition of crude product[a]				Yield of 2
	1 (g/mM)	RB[b] (mg/mol%)	(hrs)	1 (%)	2 (%)	3a (%)	4a (%)	(%)[c]
11	29.0/1098	657/0.22	35	—	95	5	—	35
12	28.6/1084	650/0.21	22	—	96	4	—	60
13	29.6/1118	648/0.21	21	—	85	5	10	24
14	29.6/1118	744/0.24	36	6	83	7	4	23
15[d]	29.9/1131	786/0.25	19	—	81	6	13	24

[a] Determined by ^{1}H-NMR (±2%). [b] RB = rose bengal disodium salt. [c] Isolated yield after crystallization. [d] Samples (ca. 1 ml) taken every hour during the first 9 hours.

As mixing is mainly provided through gas purging and magnetic stirring, mass transfer and oxygen saturation may differ between experiments, which naturally impacts process efficiencies. The large quantities of photodegradants also complicated the crystallization process and thus, the isolated yields of hydroxyfuranone (**2**) ranged widely from 23-60% [35]. Although all experiments were conducted under similar conditions, the highest yield of **2** of 60% was obtained after 21 hours of irradiation (**Table 2**, Entry 12). The methoxy-derivative **3a** was detected in all transformations, but its amounts remained low with ≤7%. In contrast, the open (*E*)-methyl 4-oxobut-2-enoate (**4a**) was only observed in three cases, but in lower quantities ≤13% (Entries 13-15). Despite the fluctuating yields, the immersion-well setup readily produces multi-gram amounts of pure **2** due to its larger size and more powerful lamp. Advanced models with dedicated gas feeding or mixing elements may further improve performances [38, 42].

The progress of the photooxygenation in Entry 15 was furthermore monitored for the first 9 hours. Samples were taken every hour of irradiation and were analysed by ^{1}H-NMR (**Figure 3**). In contrast to the reaction conducted in the Rayonet reactor and in ethanol, the amount of **1** decreased more slowly and irregularly due to the need to refeed bleached sensitizer. Noteworthy, no methoxylated byproducts **3a** or **4a** were detectable in the first 5 hours. A conversion of approx. 90% was reached after 6 hours. Subsequent analyses during the final 3 hours revealed irregular amounts of **3a** and **4a**, again suggesting their formation during sample evaporation and storage.

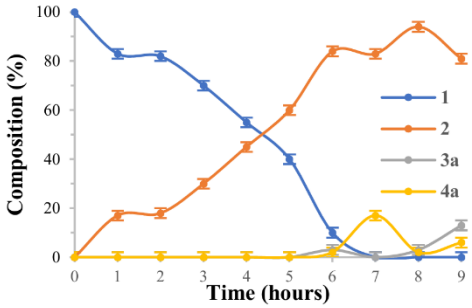


Figure 3. Composition over time profile (Entry 15).

3.1.3 Demonstration-scale Illuminations in the Flatbed Reactor

The large demonstration-scale solar photooxygenation experiments (**Scheme 1**) demanded a scale-up from 0.1-0.25 litres to up to 8 litres. Solutions of furfural (**1**), rose bengal and ethanol (technical or absolute) were prepared in the flatbed reactor and exposed to natural sunlight (**Figure 1c**) [18, 45, 46]. Atmospheric air was bubbled through the reaction mixture, which provided turbulent mixing and oxygen saturation. Cooling of the reaction mixture was achieved by circulation through an external cooling loop, although temperatures inside the flatbed readily reached 23-46°C. Since illumination conditions such as sunlight intensity, outdoor temperature and atmospheric oxygen content naturally vary depending on time and season, all four solar transformations were monitored. Samples of 2 ml volume were collected at designated reaction times, and their chemical compositions were subsequently determined by ^{1}H-NMR spectroscopy. After completed exposure, the final reaction mixture was carefully evaporated, dried and again analysed for its composition (**Table 4**). Due to the large volumes of solvent and significant amounts of formic acid (B.p.: 101°C) generated, complete evaporation and drying proved

time-consuming and challenging. The isolation of **2** was attempted by either seeding with pure crystals and refrigeration or freeze crystallization using liquid nitrogen.

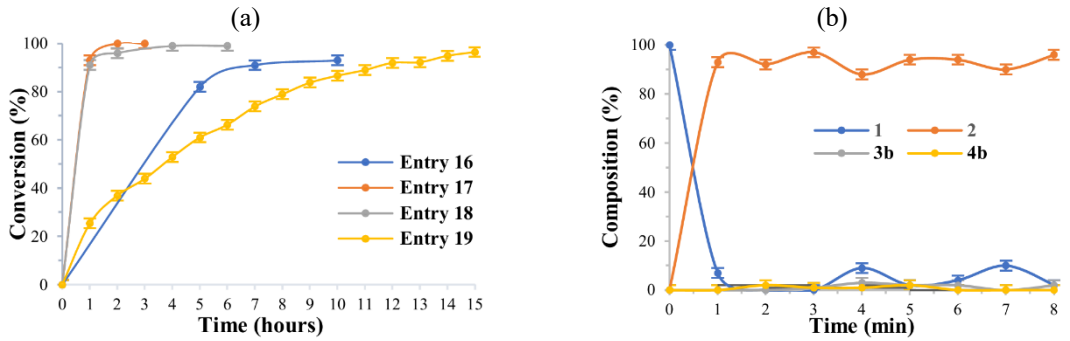
Table 4. Experimental parameters and results for solar illumination in the flatbed reactor.

Entry	Loadings			Time	Temp.	Composition of crude product[a]				Yield of
	1 (g)	RB[b] (g)	EtOH (l)	(hrs)	(°C)	1 (%)	2 (%)	3b (%)	4b (%)	2 (%)[c]
16[d]	274	5.3	7.0[e]	12	36-43	7/3	71/68	20/27	2/2	30
17[d]	247	6.1	7.5[e]	9	23-33	2/1	92/67	2/25	—/7	25
18[d]	260	6.5	7.9[f]	11	27-30	9/8	89/41	2/36	—/15	42 (**3b**)[g]
19[d]	282	10.4	7.5[e]	18	33-46	5/2	70/61	23/29	2/10	49

[a] Determined by ^{1}H-NMR (±2%) for final sample/dried crude product. [b] RB = rose bengal disodium salt. [c] Isolated yield after crystallization. [d] Samples (ca. 2 ml) taken in regular intervals. [e] Technical (96%). [f] absolute. [g] After subsequent pseudo-esterification of crude product (see section 3.2.1).

Entries 16-18 were each conducted over two days with 2-7 hours of exposure daily. In contrast, Entry 19 ran for three days with 6 hours of illumination each day. All solar photooxygenations achieved high conversions of furfural (**1**) of >90%. While the initial analyses of the product samples showed good to high selectivities for hydroxyfuranone (**2**) formation, these dropped notably for the final product batches after complete evaporation and drying. For Entry 18, for example, the amount of **2** decreased from 89% to 41% during workup and hence, all crystallization attempts of **2** failed due to the increased amounts of byproducts **3b** and **4b**. The crude product from this experiment was thus subjected to further pseudo-esterification to ethoxyfuranone **3b** (see chapter 3.2.1), which was then isolated in 42% yield. In all other cases, material losses were again unavoidable during the crystallization, filtration and washing processes [35]. The highest isolated yield was obtained for Entry 19 with 49% or 144 g of pure **2**, although this experiment experienced the highest temperatures of up to 46°C. The absence of water showed no significant impact on photooxygenation performances as seen from Entry 18, and conversion rates and selectivities were found similar to those of Entry 17. The slightly shorter illumination period of 9 vs. 11 hours in the latter experiment may result from the improved solubility of rose bengal in technical ethanol and hence the improved transparency of the solution.

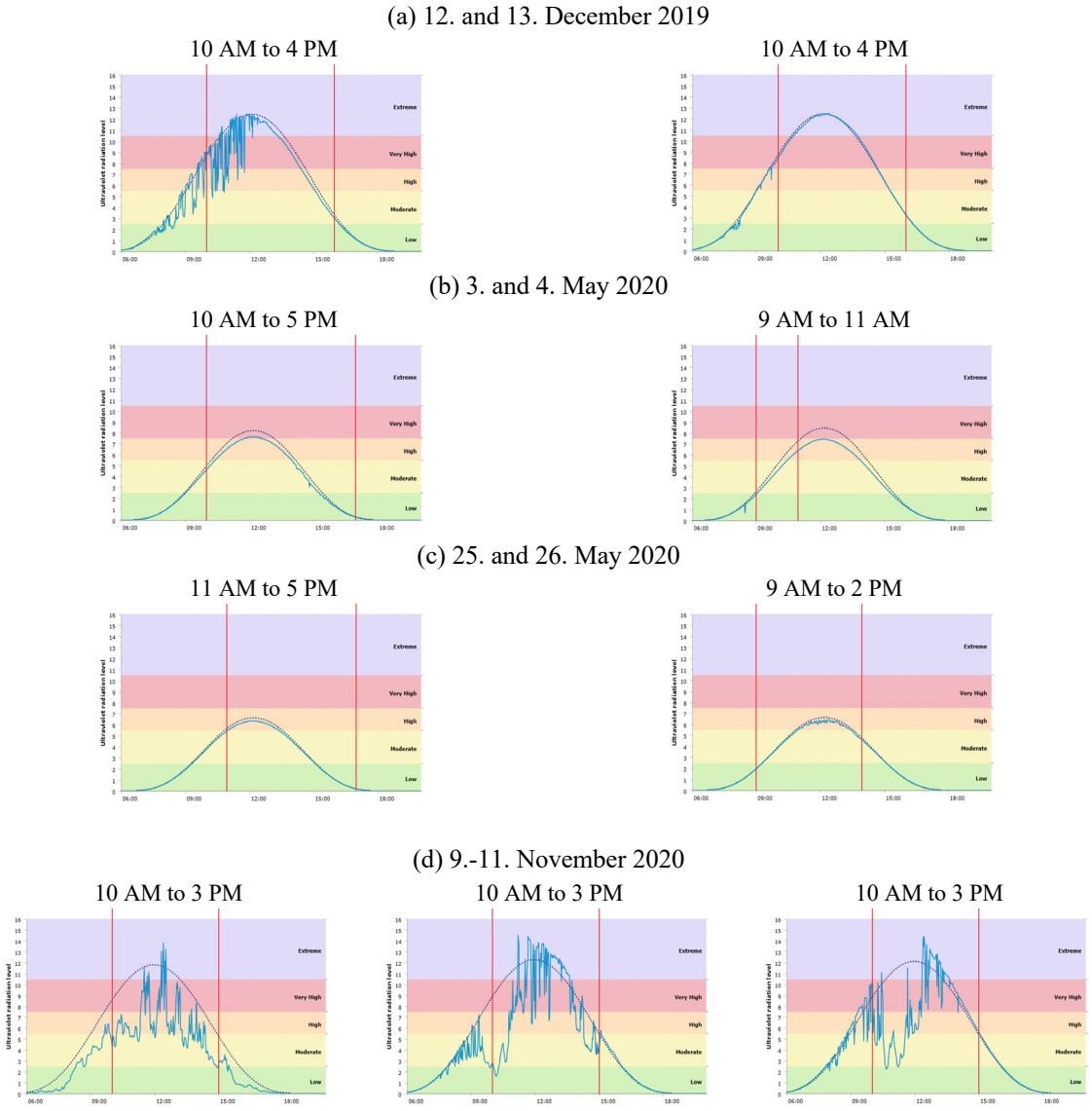
The four solar experiments were routinely sampled and analysed to determine their conversion over time profiles (**Figure 4a**). Entries 17 and 18 proceeded rapidly and showed near complete conversions of >90% already after one hour of exposure. In contrast, Entry 16 displayed a somewhat slower conversion, but reached a consumption of **1** of 82% after 5 hours in direct sunlight. A slow but steady conversion of furfural **1** over the first 15 hours was noted for Entry 19 instead. The composition profile of Entry 17 is furthermore exemplarily shown in **Figure 4b**. After the first hour, the composition of the reaction mixture remained relatively constant over the next 7 hours of exposure. After workup, however, the proportion of **2** had dropped from 92% to 67%, while the amount of ethoxyfuranone (**3b**) had increased from 2% to 25%. A similarly rapid conversion of **1** was observed for Entry 18, while Entries 16 and 17 proceeded more slowly (not shown).



Figures 4. (a) Conversion over time profiles. (b) Composition over time profile (Entry 17).

The different solar performances most likely resulted from the varying sunlight conditions during each experimental phase (**Figures 5**). Clearer and sunnier weather conditions naturally initiated better conversion rates as evident from solar Entries 17 (**Figure 5b**) and 18 (**Figure 5c**). In contrast, less favourable solar conditions

demanded prolonged illuminations as shown by solar Entries 16 (**Figure 5a**) and 19 (**Figure 5d**). Different sensitiser concentrations also impacted on the transparency and hence light penetration efficiency of the reaction mixture. Fluctuating oxygen saturation due to temperature differences may furthermore alter singlet oxygen generation. While the simple flatbed reactor operated satisfactory and produced large quantities of **2**, it would benefit from better cooling and improved gas-feeding inside the illuminated reaction chamber.

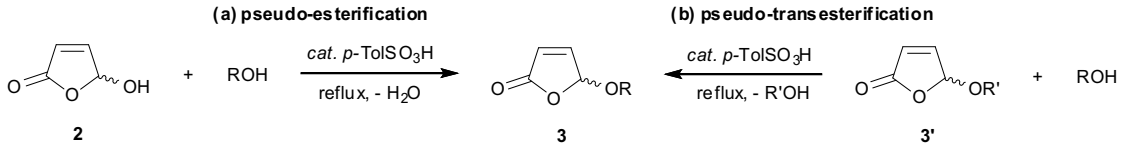


Figures 5. UV indices (ARPANSA) during solar exposures: (a) Entry 16. (b) Entry 17. (c) Entry 18. (d) Entry 19. Vertical red lines represent the experimental time frames.

3.2 Pseudo-Esterification and -Transesterification Experiments

Due to the somewhat unsatisfactory and unreliable yields of hydroxyfuranone (**2**) achieved through photooxygenation, its alkoxy-derivatives **3** may represent alternative commodity and platform chemicals. Alkoxyfuranones (**3**) are readily available from **2** through acid-catalysed pseudo-esterification (**Scheme 3a**) and consequently, a variety of reaction protocols have been described [20, 25, 30]. To complete these transformations, the water generated is commonly removed by azeotropic distillation using chloroform or toluene. In addition, pseudo-transesterification of methoxy- or ethoxyfuranone (**3a,b**) may serve as an access to more complex alkoxylated analogues (**Scheme 3b**) [22, 47, 48]. Both conversion processes also represent an interesting option for the organic waste streams of the photooxygenation protocol. In particular, the liquid filtrates collected mainly

contained residual hydroxyfuranone (**2**) and larger amounts of either methoxy- (**3a**) or ethoxyfuranone (**3b**), respectively.



Schemes 3. (a) Pseudo-esterification and (b) pseudo-transesterification to 5-alkoxyfuranones.

3.2.1 Pseudo-Esterification Reactions

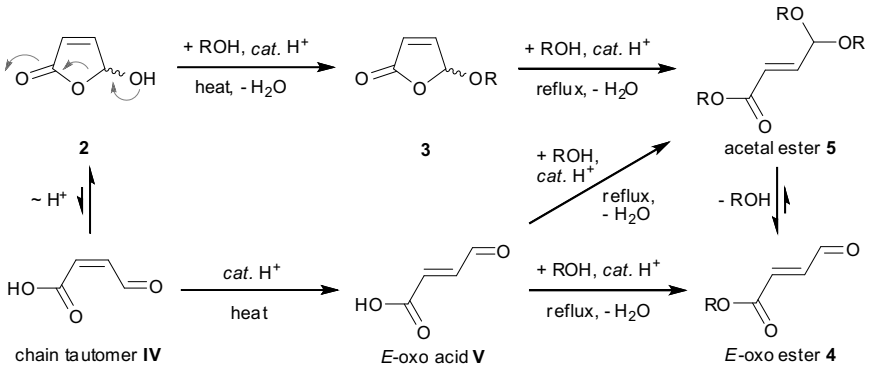
Heating of hydroxyfuranone (**2**) in chloroform with either methanol, ethanol or *n*-butanol and in the presence of catalytic amounts of *para*-toluenesulfonic acid monohydrate readily produced the desired alkoxyfuranones **3a,b** and **e** (**Scheme 3a**). After 5-6 hours of azeotropic distillations, the formation of water had generally ceased, the reaction mixtures were neutralized, and the solvent and residual alcohol were removed by careful evaporation. Analyses of the crude reaction mixtures confirmed complete conversions and minor amounts of ≤20% of the corresponding ring-opened (*E*)-alkyl 4-oxobut-2-enoates **4**. Subsequent vacuum distillation or flash chromatography furnished compounds **3a,b** and **e** in reduced isolated yields of 36-62% due to purification losses (**Table 5**) [35].

Table 5. Experimental parameters and results for pseudo-esterifications (150 ml of $CHCl_3$, 0.5 g *p*-$TolSO_3H$).

Entry	2 (g/mmol)	ROH (ml/mmol)	Time (hrs)[a]	Yield of 3 (%)
20	18.8/187.9	MeOH, 8.4/207.1	6	57 (**3a**)[b]
21	10.3/102.9	EtOH, 6.6/113.2	6	62 (**3b**)[b]
22	2.02/20.2	^{n}BuOH, 2.1/22.9	5	36 (**3e**)[c]

[a] Time until formation of water had ceased. [b] After vacuum distillation. [c] After flash chromatography.

Several pathways for the formation of alkoxyfuranones and their derivatives have been proposed (**Scheme 4**) [25]. Hydroxyfuranone (**2**) partially exists in its chain tautomeric form **IV** [49], which can undergo acid-catalysed isomerisation to its corresponding *E*-oxo acid **V**. Subsequent esterification and acetalization furnishes the commonly observed (*E*)-alkyl 4-oxobut-2-enoates **4** and their analogue acetal esters **5** [50, 51]. Alternatively, direct pseudo-esterification of hydroxyfuranone (**2**) produces the analogue alkoxy derivatives **3**. Prolonged and extreme heating in the presence of excess alcohol generates the related acetal esters **5**, which subsequently transform into their equivalent *E*-oxo esters **4** [25]. Gassama and co-workers, for example, conducted azeotropic distillations of **2** with long-chain alcohols in two different solvents. Heating in toluene for 72 hours predominantly furnished the *E*-oxo esters **4**, while refluxing in chloroform for 1 hour favoured the generation of the alkoxyfuranones **3** instead [30]. To further minimize the formation of the acetal esters **5**, the respected alcohols for pseudo-esterification are used in equimolar or in slight excess amounts.



Scheme 4. Pseudo-esterification of 5-hydroxyfuranone (**2**) and subsequent pathways.

The pseudo-esterification protocol was furthermore applied to the reaction mixture obtained from solar Entry 18. Its crude product mass contained significant amounts of the desired **2** that could not be isolated by crystallization. Thus, the complete conversion of **2** into ethoxyfuranone **3b** by azeotropic distillation was attempted. The crude reaction mixture (345 g) containing 41% of **2** (approx. 1.4 mol) was dissolved in ethanol (85 ml, 1.48 mol) and 250 ml of chloroform. After addition of *para*-toluenesulfonic acid monohydrate (1.5 g), the solution was refluxed for 12 hours using a Dean-Stark apparatus. Subsequent neutralization, drying and evaporation yielded a refined product mass. ^{1}H-NMR analysis of the crude material confirmed that complete conversion of **2** had indeed occurred. However, besides small amounts of unreacted furfural (**1**) from the solar experiment, the mixture mainly consisted of ethoxyfuranone (**3b**) and its oxo ester **4b** in amounts of 53% and 39%. Hence, the amounts of **3b** and **4b** had increased by 17% and 24%, respectively, through this simple blending process. Careful successive vacuum distillation produced **3b** in a yield of 42% or 75 g and with a purity of 98%. This result clearly shows that further utilization of the waste streams from the photooxygenation process is feasible. However, the selectivity towards alkoxyfuranone (**3**) production remains challenging due to subsequent thermal rearrangement into the corresponding oxo esters **4** and acetal esters **5**. Heat management is thus crucial for both, the photooxygenation and pseudo-esterification process. However, as the open *E*-oxo esters **4** are versatile building blocks themselves [30, 51], exhaustive pseudo-esterification under more extreme conditions may provide a future access to these materials.

3.2.2 Pseudo-Transesterification Reactions

Since long-chain and branched alkoxyfuranones (**3**) represent important fragrance components [20] or starting materials for surfactants [25, 30], the pseudo-transesterification of methoxy or ethoxyfuranone **3a** and **b** represents an interesting pathway to these compounds. Thus far, only isolated examples for the synthesis of a versatile chiral menthoxyfuranone building block through pseudo-transesterification have been reported [22, 47, 48]. These methods utilize heating with equimolar amounts of menthol in the absence or presence of acid. For this study, a modified protocol of the pseudo-esterification described in chapter 3.2.1 was applied to the conversion of ethoxyfuranone (**3b**). Azeotropic distillation of **3b** in chloroform and either *n*-hexanol, cyclohexanol or dodecanol with catalytic amounts of *para*-toluenesulfonic acid monohydrate for 15 hours furnished the corresponding alkoxyfuranones **3f-h** (**Scheme 3b**). Inspection of the crude materials revealed complete conversion of **3b**. However, substantial amounts of the isomeric (*E*)-alkyl 4-oxobut-2-enoates **4f-h** of 25-53% were also noted, probably due to the nonoptimal prolonged heating times. For *n*-hexanol, small amounts of the acetal ester **5f** of 4% were furthermore detected (Entry 23). Purification by flash chromatography subsequently gave the alkoxy derivatives **3f-h** in reduced but moderate yields of 38-63% (**Table 6**) [35]. Thus, pseudo-transesterification from the more readily accessible ethoxyfuranone (**3b**) offers an alternative general access to more complex alkoxy analogues.

Table 6. Experimental parameters and results for pseudo-transesterifications (150 ml of $CHCl_3$, 0.5 g *p*-$TolSO_3H$).

Entry	3b	ROH	Time	Composition of crude product[a]			Yield of 3
	(g/mmol)	(ml/mmol)	(hrs)	3 (%)	4 (%)	5 (%)	(%)[b]
23	11.3/88.2	[n]HexOH, 12.1/97.1	15	43	53	4	38 (**3f**)
24	10.2/79.6	[c]HexOH, 9.2/88.2	15	75	25	—	63 (**3g**)
25	25.6/200.2	[n]DodecOH, 49.4/220.0	15	70	30	—	60 (**3h**)

[a] Determined by ^{1}H-NMR (±2%). [b] After flash chromatography.

4 CONCLUSIONS AND OUTLOOK

The photooxygenation of sugarcane derived furfural (**1**) represents an interesting example for the sustainable manufacturing of important building block chemicals. Irradiations with artificial or natural sunlight furnish the versatile building block chemical hydroxyfuranone (**2**) in yields of 30-52%. The isolation and purification of **2** remained challenging due to rapid thermal follow-up reactions. Nevertheless, demonstration-scale solar reactions produced large multi-gram quantities of pure hydroxyfuranone (**2**). Successive pseudo-esterification of **2** by azeotropic distillation furnished the corresponding alkoxy derivatives **3a,b** and **e** in moderate isolated quantities of 36-62%. Likewise, a crude solar photooxygenation product served as a suitable resource for larger scale pseudo-

esterification to ethoxyfuranone (**3b**). A different approach successfully investigated pseudo-transesterifications of **3b** to the more complex alkoxyfuranones **3f-h** in yields of 38-63%. For all reactions studied, successive ring-openings and acetalizations were observed as dominant and difficult to control side-reactions. Despite this, the photochemical and thermal reactions investigated in this study add to the of growing number of transformations of renewable materials to versatile and valuable commodity chemicals [1-4, 18, 25].

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Investigation of Teaching Platforms Used in Grades 11 and 12 Physics Education in Papua New Guinea

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Abstract: ICT in education uses technology to enhance and facilitate teaching and learning processes. It involves the use of various digital tools, platforms, and resources to support teaching and learning activities. The introduction of ICT in education has bridged the gap between traditional teaching methods and modern, technology-driven learning. Through the integration of ICT, students can now access a wealth of information and resources online, collaborate with peers and teachers in real-time, and even engage with interactive learning materials. In our study, we selected physics education because physics is the most difficult science subject. Status of ICT and the types of teaching platforms used in teaching and learning physics at grades 11 and 12 were determined by conducting a survey on first year university physics. ICT status was found to be good for the schools run by the state. Recommendations have been proposed to narrow the disparities in ICT status and the teaching platforms used in cities, urban towns, district towns and rural disadvantaged locations.

Key words: Transitional Physics Education, Traditional Pedagogy, ICT, Online Teaching and Learning

1. INTRODUCTION

Papua New Guinea is a developing country in the Pacific. With the population of over 10, 000, 000, about 20% of the population lives in urban centers while 80% of it lives as subsistence farmers in the rural parts of the country. The country is rich in natural resources but faces challenges of high and rugged mountains and valleys, thick forests, fast and deadly flowing rivers and deep muddy swamps. Given as one of the most challenging landscapes of the countries in the world, fair and effective distribution of basic government services especially in the education system across the country remains a significant challenge.

The structure of the government system of Papua New Guinea is that we have National Government, Provincial Government and Local Level Government in the order from top to the bottom respectively. The National Government prepares and passes the yearly national budget where Provincial Governments are funded to deliver basic government services in the sectors such as education, health etc. The Provincial Governments then fund their respective Local Level Governments to deliver the basic government services such as education to the people of this country at the village levels.

All the schools at early childhood, primary, high school and secondary school levels receive their funding from the National Government through their respective Provincial Governments and Local Level Governments. The schools use the funds received for infrastructure and curriculum developments and the overall management and administrative purposes.

All the schools in Papua New Guinea come under the two categories as School Authority and School Locations. Under the School Authority we have Agency, Private and State. Agency covers the schools run by the churches while the local private citizens and international organizations run the Private schools. The government runs state schools. Under the School Locations we have City, Urban Town, District Town and Rural Disadvantaged schools. City schools have steady access of water, electricity, internet, e-library and mobile networks. Urban Towns are provincial centers and have both water and electricity but lack one of the other three basic learning infrastructures. District Towns are small compared to Urban Towns and have steady access of water and electricity. However, they lack two out of the other three learning facilities. Rural Disadvantaged schools only have water and electricity but suffer from lack of the other three vital learning enhancement infrastructures.

All the Papua New Guinean students entering different technical colleges and universities in this country as first year students after completing Grade 12 level of education come under one of the streams of these two school categories – School Authority and School Location. Transitional physics education from Grade 12 education to the first-year university studies in physics in Papua New Guinea requires attention. This is because physics is known as the most difficult, unifying and multidisciplinary subject of science. The first-year university students taking physics in Papua New Guinea are also deeply rooted in and raised in their local cultural diversities and complexities.

Online teaching and learning particularly at the university level is fast becoming a common trend at the global scale. Papua New Guinea as part of the global community has embraced online teaching and learning in its universities. Teaching platforms are online tools that teachers, academics and instructors use with the aid of digital technology in academia. The online tools facilitate the creation, delivery, and management of educational content. These platforms provide a digital space for instructors to share materials, interact with students, and assess learning. They also feature video conferencing, assignment submission and progress monitoring. Antonio & Castro (2023) sighted in Ramaila (2024) stated that 'The integration of technology in education has revolutionized traditional teaching methodologies, offering innovative tools and resources that enhance the learning experience. In the realm of physics education, technology plays a pivotal role in bridging theoretical concepts with practical applications, making abstract principles more tangible and accessible to students. Physics Education Technology simulations, virtual labs, interactive software, and other digital resources have emerged as transformative pedagogical tools that provide dynamic and engaging learning environments' (p. 1).

The first-year university students taking physics come from different cultural, school authorities and school locations back grounds. The challenges they face and efforts they make to adapt to the conditions of their new home environment far from their family homes is a severe test to every individual student. One of the factors that contribute to successful transition into first-year university physics studies is the relevant and appropriate teaching platforms they have acquired in grades 11 and 12 physics from their previous respective schools. Bhat (2023) sighted in Ramaila (2024) stated that 'Educational technology in physics allows for differentiated instruction, catering to the diverse learning needs and paces of students' (p. 2).

Kebibeck, Piatek-Jimenez & Medina (2024) found that the most prevalent challenges faced by first-year university physics students are difficult course content, pedagogy, competitive environment, lack of community, and lack of mentorship. Teaching platforms aspect of physics education is critical to effective and successful delivery of curriculum content. This enhances physics students' learning resulting in academic success.

Choosing physics to investigate variations in teaching platforms used in different locations of the schools under different authorities is critical for improvements in physics education and successful transitions into university studies. Main driving factors that lead to improving physics education are high failure rates in first-year university physics, declining statistics of students' enrollments in high school and university physics, connection between physics and natural phenomena both from scientific and cultural intelligence perspectives and the invaluable contributions that physics makes in all sectors of development in the world.

Some intervention strategies are required to arrest the global trend of high failure rates in physics at high school and first-year university levels. Ramnarain & Molefe (2012) reported that 'A high failure rate at first year physics is often attributed to the lack of readiness of high school students to pursue such studies' (p. 1). Unqualified physics teachers and not being able to see the relevance of physics with daily life, application in different disciplines and career prospects are also factors that contribute to this trend. Saeed M & Khan A, W (2021) also found that 'secondary school science students' conceptual knowledge about content related to physics is less' (p. 14).

Dodd T (2024) reported a catastrophic decline in the number of students studying physics in senior high schools in Australia between the years 2015 and 2023. The report further highlighted that if the trend continued there would be no female school leavers qualified to study physics at university by 2032 and no males by 2035 with Australia losing the expertise it needs to be competitive as an advanced economy. Physics experts play a critical role in medicine, astronomy, energy transition, nuclear industry and climate science etc.

In this paper we determined which schools under School Authority and School Locations used Conventional, Blended and Fully Online teaching and learning in Papua New Guinea. We also found the ICT status at the respective settings of the schools. Data collection was administered by conducting a survey among the first-year university students taking physics. The data collected was entered into Google Forms as a survey

administration software and used the Google Sheets for effective sorting in spreadsheets. We also proposed measures to improve physics education in secondary schools and first year university studies by embracing ICT and blended teaching and learning platforms.

Table 1: The number of students who took part in the study from the City, Urban Towns, District Towns and Rural Disadvantage schools under the authority of the Agency, Private and State in Papua New Guinea.

		SCHOOL LOCATION				TOTAL	TOTAL
SCHOOL AUTHORITY		CITY	URBAN TOWN	DISTRICT TWON	RURAL DISADVANTAGE		
AGENCY	Male	7	5	9	9	30	
	Female	12	3	7	6	28	58
PRIVATE	Male	2	0	1	0	3	
	Female	2	1	0	0	3	6
STATE	Male	29	39	41	8	117	
	Female	24	14	6	3	47	164
TOTAL	**Male**	38	44	51	17	**150**	
	Female	38	18	13	9	**78**	**228**
	TOTAL	76	62	64	26	**228**	

The number of students who took part in the study is given in Table 1. The survey questionnaire provided a section on ICT and Teaching Platforms. The participants responded according to their physics learning experiences from their previous schools. Participants' responses were categorized under school authority and school locations using legends. The data collected was tabulated and further transformed into respective graphs showing the percentage weightage of the responses.

Below are the legends:

A1: Agency City
A2: Agency Urban Town
A3: Agency District Town
A4: Agency Rural Disadvantaged
P1: Private City
P2: Private Urban Town
P3: Private District Town
P4: Private Rural Disadvantaged
S1: State City
S2: State Urban Town
S3: State District Town
S4: State Rural Disadvantaged

RESULTS

ICT Status

Put a tick (√) in the appropriate boxes below.

49. What was the status of ICT in your last school?

	Good ☐	Poor ☐	Nill ☐
A1:	14	3	2
A2:	4	2	2
A3:	10	4	2
A4:	0	9	5
P1:	4	0	0
P2:	0	1	0
P3:	0	0	1
P4:	0	0	0
S1:	35	12	7
S2:	38	8	7

S3:	14	17	12
S4:	4	4	3

Table 2: Percentage responses on ICT status by School Authority.

SCHOOL AUTHORITY	ICT Status		
	Nill	**Poor**	**Good**
AGENCY	5.8 %	7.1 %	12.5 %
PRIVATE	0.004 %	0.004 %	1.8 %
STATE	13 %	18.3 %	40.6 %

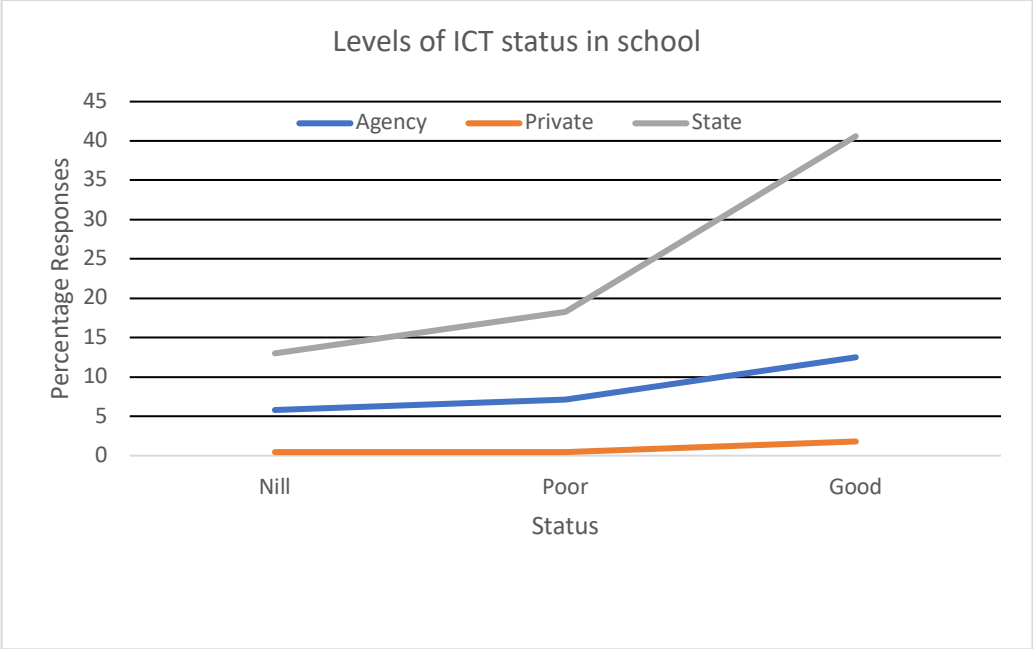

Figure 1: Percentage levels of ICT status.

Table 3: Percentage responses on ICT status by School Locations.

SCHOOL LOCATION	ICT Status		
	Nill	**Poor**	**Good**
City	3.9 %	6.6 %	23 %
Urban Towns	3.9 %	4.8 %	18.4 %
District Towns	6.6 %	9.2 %	10.5 %
Rural Disadvantaged	3.5 %	5.7 %	1.8 %

54. What teaching platforms did your physics teacher use to deliver lessons in your last school?

Fully online ☐ Blended ☐ Fully conventional ☐

A1:	0	5	16
A2:	0	0	8

A3:	1	4	11
A4:	0	2	12
P1:	0	4	0
P2:	0	0	1
P3:	0	0	1
P4:	0	0	0
S1:	0	13	38
S2:	1	22	31
S3:	0	12	35
S4:	0	3	8

Table 4: Responses on Teaching Platforms by School Authority and Locations.

SCHOOL		**TEACHING PLATFORMS**		
AUTHORITY	**LOCATION**	**Fully Conventional**	**Blended**	**Fully Online**
AGENCY	CITY	16	5	0
	URBAN TOWN	8	0	0
	DISTRICT TOWN	11	4	1
	RURAL DISADVANTAGE	12	2	0
PRIVATE	CITY	0	4	0
	URBAN TOWN	1	0	0
	DISTRICT TOWN	1	0	0
	RURAL DISADVANTAGE	0	0	0
STATE	CITY	38	13	0
	URBAN TOWN	31	22	1
	DISTRICT TOWN	35	12	0
	RURAL DISADVANTAGE	8	3	0

DISCUSSION

Table 2 shows that schools under the state authority embrace ICT services more than agency and private schools. Table 2 further shows the lowest percentages of ICT status under private authority. One of the reasons for this observation is due to the lowest number of participants from private schools that took part in the survey. Private schools operate mostly in cities and urban towns and are absent in district towns and rural disadvantage settings given the economic nature of their school management and administration. This study highlights the critical concern that rural disadvantaged schools under all three school authorities suffer from little to no access to ICT services.

Table 4 shows that all schools under the three school authorities and four different locations are dominated by traditional method of teaching and learning. In this study, it refers to chalkboard writing and face-to-face teacher to student teaching and learning. While the study shows a relatively small indication of embracing blended teaching and learning, almost all schools in Papua New Guinea are yet to explore and fully embrace the benefits of fully online teaching and learning.

ICT services are vital part of shifting from traditional pedagogical strategies to student-centred teaching and learning through blended and fully online teaching and learning. The global trend of education in this digital age is to give students opportunities to be responsible and take ownership of their learning. The findings of this study highlight critical need areas to be improved particularly for grades 11, 12 and first-year university transitional physics education. Below are some of the recommendations for transformational physics education. Some of the recommendations to enhance the cultural Intelligence are given below.

- Run upskilling training to physics teachers on blended and fully online teaching and learning.
- Government and private organizations to support schools with ICT and internet facilities.
- First-year physics students to have orientation on fully online teaching and learning platforms.
- Government and private organizations to support universities with digital infrastructure.
- Encourage peer collaborations in fully online teaching and learning.
- Universities and secondary to work collaboratively for transitional physics education.

CONCLUSION

There is a significant disparity in the ICT status between the schools under different authorities and locations. Students attending rural disadvantaged schools under all three school authorities are significantly marginalised from accessing basic and useful ICT services. A critical highlight in this study is the significant gap between the secondary schools and universities in terms of information and resources sharing for transitional physics education. While universities in Papua New Guinea have embraced digital technology to support and promote blended and fully online teaching and learning, high schools and secondary schools continue to hold onto and practice traditional pedagogy. We recommend secondary schools physics teachers upskilling to blended and fully online teaching and learning platforms. Close collaboration between universities and secondary schools is highly recommended for successful transitional physics education into first-year university studies.

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