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LOWERING THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF THE SINGLE USE PERSONAL PROTECTIVE MATERIALS

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Abstract

Personal protective equipment has been widely used by individuals to fight COVID-19 outbreaks. This has caused a substantial increase in solid waste generation rates resulting from a single use of these materials and puts economic pressure on families and governments. However, finding sustainable and affordable alternatives to the basic materials used is essential in strengthening the protection of societies during epidemics or any similar conditions in the future, as well as strengthening the economy of societies by establishing self-employment and reducing expenditures on consumables. This study provides an assessment of sustainable alternatives to personal protective materials and tools. The assessment has been conducted in two areas in Jordan, which also include refugee camps, through an online questionnaire and an interview with representatives. The results revealed that the hand/surface hygiene and PPE were not easily accessible during lockdowns and were expensive due to problems in the supply chain. 80% of the individuals were suffering from the inability to purchase the supplies, especially the families with daily income. It has been proved that basic materials such as masks and hand hygiene can be locally produced and reused. There has been a recommendation (82% of respondents) to perform training to the communities in the production of basic materials such as hygienic and protection materials and providing communities with essential raw materials for production.

Key words: Covid-19, PPE, protective measures, solid waste, sustainable materials

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1. Introduction

There have been significant effects on the everyday life of the global population caused by the COVID-19 pandemic and the associated emergency measure followed to protect public health (Hartley et al., 2022; Ranjitkar et al., 2022). These measures varied among different population groups based on their location and their economic power and focus but are not limited to mobility restrictions, distancing, use of PPE, and awareness. However, there have been a variety of perceptions, practices, and experiences among populations among groups of different ages, gender, and family status (Vatavali et al., 2020). These

may impact the recommended action to specify best measures, reporting of the community response experiences, and design strategies to minimize associated costs related to any strategies to mitigate the impacts of any similar emergencies in the future (Wu et al., 2022).

The World Health Organization (WHO) and governments worldwide have recommended the use of personal protective equipment (PPE) and hand hygiene as the first line of defending themselves against COVID-19 (Ghanchi, 2020; Koh, 2020; Panigrahi et al., 2021). While the virus is transmitted especially through droplets, most of the protective equipment is mechanical protective defenders (Duan

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et al., 2021; Unoki et al., 2020). However, there has been no evidence that a single PPE offered the best protection against COVID-19 (Alhazzani et al. 2020; Min et al., 2021; Sahu et al., 2020). Most of the PPE is produced and supplied by China, and this supply has come to a halt during the dramatic infection spread in the country (Bown, 2022). This disruption in the supply chain has been in a combination with exponentially high demand levels, restrictions on the travel sector, PPE guidelines updates, and lockdowns. This, therefore, has created a lack of PPE in all vital sectors such as the medical and industrial sectors and increases the attempt for PPE reuse options (Hu et al. 2023; Jessop et al., 2020; Torre Bayo et al. 2023).

Due to the huge demand for PPE that reached an unprecedented level during the pandemic peak outbreak, there has been a substantial increase in the PPE industry sector (Singh et al., 2020). However, most PPE is made from plastic-based polypropylene nonwoven fabrics and is single-use equipment (Uddin et al., 2022). The single-use PPE leads to the disposal of large volumes of plastic waste (Barman, 2022; Silva et al., 2021). This volume may have a detrimental environmental impact as there is no sufficient infrastructure for handling a large volume of disposed contaminated single-use PPE and minimizing its environmental impact (Karim et al., 2020; Patel et al., 2022; Uddin et al., 2022). There have been many attempts to find solutions, minimize solid wastes generated from PPE use during the pandemic and study the environmental impacts (Aydin and Cifci, 2022; Rasin et al., 2022; Zarikas et al. 2020). It has been shown that the production of synthetic fibers has about 70% of the carbon emitted globally during producing textile materials (Fadare and Okoffo, 2020). The long-term impact of disposing of fabrics originating from fossil fuels has been shown in many studies as its property of not readily biodegradable and can impact human health (Fadare and Okoffo, 2020; Uddin et al., 2022). One of the most serious drawbacks of the COVID-19 outbreak is the environmental concerns especially the micro-plastic pollution and solid waste impacts (Karim et al., 2020; Pourghaznein and Salati, 2020). However, many environmental problems appeared during the pandemic including marine and terrestrial ecosystems (Feng et al., 2020).

The use of sustainable PPE may minimize the per capita consumption rate and thus the volume of generated solid wastes (Limani et al. 2021; Silapurna, 2021). This can also benefit the environment by lowering the carbon emissions associated with production, transportation, and energy consumption during the supply processes (Monolina et al., 2022; Zhao et al., 2022). Reusable PPE is expected to benefit the economy of both personal and national scales (Baker et al., 2020). This can be expected by reducing the amount of budget allocated for buying the PPE for households. However, the environmental and economic benefits of reusable PPE may be duplicated if they are made by the local community. There have been no studies addressing the effect of locally producing reusable PPE on environmental and

economic factors. This study is designed to investigate the possibility of producing reusable PPE by the local communities, required and suggested training and preliminary materials, the feasibility of applying IoT in all processes associated with production and marketing, and if producing reusable PPE by the community will enhance self-employment programs and thus households' economy and community's responses to emergencies like COVID-19 pandemic. The concept and processes of producing sustainable PPE are addressed in this study (Fig. 1). This study is carried through out an online questionnaire and focus group discussion.

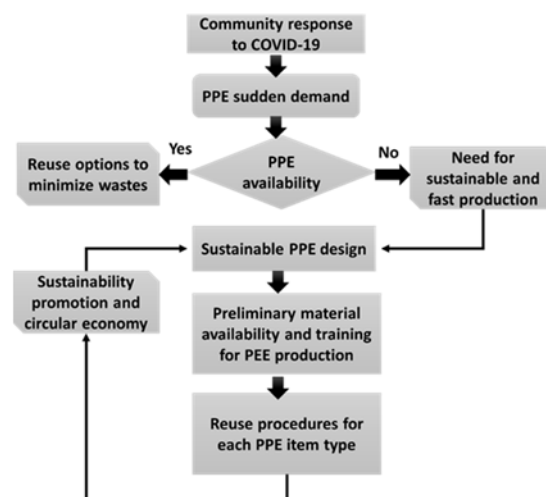


Fig. 1. Flowchart of main processes and concepts of the sudden community response to COVID-19 in term of PPE production. The processes started with the sustainable design for PPE if are not available/insufficient until the processes are end by sustainability promotion and circular economy.

2. Methodology

This study was performed during mitigating measures of the national instructions associated with COVID-19 protection actions in Jordan. This period is called the post-pandemic era where this study gets the lesson learned from the community that is associated with economic and the environmental view of using and producing PPE. The methodology consists of two distinct phases questionnaire and focused group a discussion. The latter was conducted after the questionnaire has been performed to elaborate the findings by evaluating feedback, experiences, and behaviour presented by participants. The questionnaire has been designed in three sections using the google forms service (Table 1). It has been reviewed and approved by an external reviewer and distributed through emails within the authors' contacts. This has been performed to avoid the duplication of responses. Sections of the questionnaire are designed to examine the participants' awareness and knowledge of PPE and its related economic and environmental impacts.

Table 1. Summary of questions directed to the community regarding to their knowledge, suggestions and behaviour during the pandemic. The Table detailed each section in the questionnaire and ideas that can be obtained.

<i>Topics addressed</i>	<i>Gained info</i>	<i>Multiple choice</i>	<i>Text</i>
<i>Section 1: General information and knowledge of PPE/COVID related information</i>			
Questions for community of	<ul style="list-style-type: none"> What are the most PPE have you used during COVID-19 (Gloves, Face masks) PPE that can be reused PPE that can be produced by the local community Non-affordable PPE Non-available PPE during the Pandemic 	✓ ✓ ✓ ✓ ✓	
<i>Section 2: Sustainable alternatives and community production readiness</i>			
Detailed info regarding to	<ul style="list-style-type: none"> PPE alternatives Do think that the PPE will be affordable if are produced locally If producing PPE will create job Needs for rehearsals/training outlines Preliminary materials and production machineries needed for PPE production Reusable PPE and sustainability 	✓ ✓	✓ ✓ ✓
<i>Section 3: IoT in PPE production</i>			
Questions for the community accesses to internet, marketing platforms and list of....complete the sentence?	<ul style="list-style-type: none"> The role of technology/mobile apps/internet services in determining the production strategies during emergencies Community needs for technology during emergencies Existing and suggested marketing platforms/mechanisms 		✓ ✓

The second section investigated sustainable alternatives to PPE and sociality readiness for PPE production. The third section explores the role of IoT in developing processes and actions associated with PPE production by local communities.

The survey was conducted remotely between 8 and 25 April 2022 via online Google forms services during the post-pandemic period in Jordan. The questionnaire is designed for ages over 18 years old and links were sent via authors' contact lists using social media and emails. This process avoids duplication and ineligible/incomplete responses. All data are tabulated, filtered, and analyzed by use of spreadsheet Excel software. The relationship between independent variables has been tested and the significant level of 0.05 was considered for all statistical tests. The Shapiro-Wilk normality test has been performed for parametric statistical analysis.

The participants responded to questions related to PPE recycling and they requested to answer if PPE can be produced by the local communities based on their knowledge. Quantitative questions have been designed to review what are the most expensive and not available PPE during the pandemic period. The participants were requested to provide a brief list of PPE alternatives, and how helpful they believe in launching training programs for PPE production. The questionnaire focused on what type of training themes, could enhance the knowledge and skills of the communities in terms of PPE production. These questions include direct requests to participants to suggest tools, materials, equipment, and training mechanisms that the community needs to get able to start their career in any PPE production programs. The

descriptive statistical tool Excel was used for analyzing the quantitative data.

3. Results and discussion

3.1. Hygiene materials and personal practices

About 90% of the total respondents used face masks as a protective way against virus spread. The use of face masks in most communities as a protective mechanism has references to the strong recommendations received from the WHO, governments, and local medical agencies. Furthermore, the respondents have indicated that the availability and ease of use of facemasks during the pandemic encouraged people to use them as well as they believe that face masks are safe and don't have any health impact. 98% of the total respondents have used several personal protection techniques including gloves (58%), hygienic materials (80%), and detergents (53%). The relatively low rate of using gloves during the pandemic has been linked to personal practices as gloves were used only during outdoor activities. Social distancing, regular hygienic practices, and handshaking avoidance contributed also to minimizing the consumption rates of gloves.

Respondents believe that the local community can produce hand hygiene (51%), gloves (37%), detergents (41%), and face-masks (86%). The preliminary materials required to produce face-masks such as household textiles have been available during lockdowns and the community partially produced some of these items as it has shown their potential as an effective environmental barrier (Rodriguez-Palacios et al., 2020). However, detergents were

produced by the community even before the pandemic. Most of respondents (86%) revealed that producing PPE, hand hygiene and detergents by the local community is a sustainable process and it has positive environmental reflexes. For instance, producing detergents from the available preliminary materials such as olive oil will provide job opportunities for the local community. Responses indicated that the percentage of people willing to work during emergencies and lockdowns is high. As 60% of the respondents indicated that face-masks can be reused many times before disposal, producing such a product will minimize the amount of solid waste generated during emergencies. The respondents encountered a sudden increase in prices of protective equipment; hand hygiene were the most expensive item followed by detergents, gloves, and face-masks (Fig. 2a). The high price of these materials during lockdowns referred to the unbalance between supply and demand. Hand hygiene has been partially available during lockdowns where 57% of the total responses indicated that there was a problem in the supply chains for hand hygiene, detergents, and gloves (Fig. 2b).

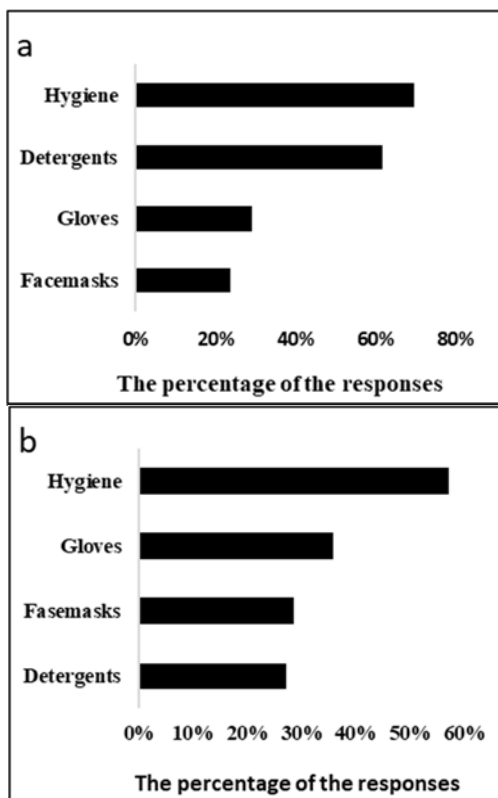


Fig. 2. The order of the most used PPE by the community during the pandemic based on the cost and availability are shown in figure (a) and (b), respectively

3.2. PPE production and community engagement

About 70% of the responses confirmed that producing PPE by the local community will be less expensive and enhances self-employment opportunities. 93% revealed that producing PPE will

create job opportunities for the local community and enhances continuous improvement in the field of entrepreneurship.

The locally produced items will be sufficiently available during emergencies and there will be no raising in prices due to the problems associated with supply chains. The community responses to emergencies will offer items based on the community's needs both quantity and quality. However, 8% of the respondents don't believe that producing items by the local community will be cheaper (Fig. 3). This percentage has indicated that there may be additional costs associated with training, tools, and technical support. These costs could impact the final costs of the products. About 80% of the respondents spent every month between 120-150 US dollars for PPE which forms 15-18% of the total income. Most of the costs (60%) were for hygiene materials and detergents.

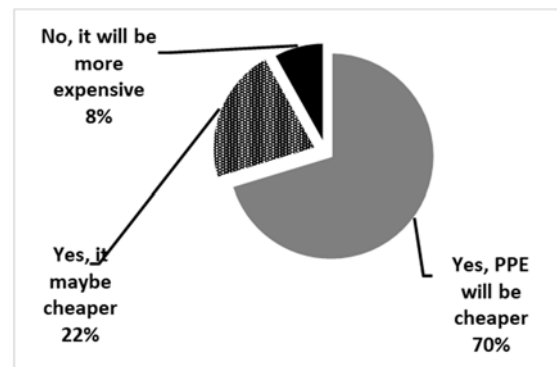


Fig. 3. Expected costs associated with producing PPE by the local community in comparison with the current costs of PPE imported by the global market

About 77% of the respondents believe that the community needs training on how to produce items. The training has to include preliminary materials used, design, validity test, any national production codes, packing, quality check, and marketing. However, 17% of the respondents conserved their answers and do not have an idea if training courses are sufficient and feasible. This has been explained by the variety of the educational level of beneficiaries, their experiences, and the complexity of the production processes. The difficulties associated with the production processes can be solved by launching a national production program where people can be involved in one or more single activities. Most of the responses (88%) agreed that the training courses and national production programs for personal protection equipment will provide for most of the community's needs during emergencies. However, several procedures and training have been suggested during the focused group discussions for the community to perform all processes associated with personal hygiene practices including protection procedures, marketing, IoT and e-services, essential tools and equipment, and cost management (Table 2).

Table 2. Training fields for communities and production process stakeholders with detailed activities and expected outcomes obtained by FGDs

<i>Training fields</i>	<i>Activity performed</i>	<i>Expected outcomes</i>
Production procedures	<ul style="list-style-type: none"> • Planning and design • Preliminary materials • Equipment and tools 	Final product with competitive quality
Health Awareness	<ul style="list-style-type: none"> • Personal hygiene • Personal behaviors • General Healthcare 	Required protection actions and PPEs
Protection practices	<ul style="list-style-type: none"> • Time and place of use • Disposal status • PPE saving • IoT and pricing 	<ul style="list-style-type: none"> • Lowering the environmental impact of the PPE disposal rate. • Minimizing the consumption rates of PPEs
Medical info	<ul style="list-style-type: none"> • Pandemic general info. • Protection mechanisms • Hygienic practices and tools • Suitable PPE • Symptoms and spread • Mechanisms and efficiency 	<ul style="list-style-type: none"> • Determination of PPE items should be used
IoT access and e-services	<ul style="list-style-type: none"> • Existing services • Platform and specifications • Help menu and first use • Data analysis and community response • Marketing Platform 	<ul style="list-style-type: none"> • Identifying the existing e-services and apps user interface • Analyzing customers' feedback and stakeholders' rating
Project management	<ul style="list-style-type: none"> • Cost management • Process management • Time management • Task management • Benefits and deadlines • Growth and budgeting 	<ul style="list-style-type: none"> • Well-managed processes and sustainability
Marketing and Packaging	<ul style="list-style-type: none"> • Delivery services • Green packaging • Competition and market needs 	<ul style="list-style-type: none"> • Items availability and green products • Customer attraction and satisfaction
Socio-economic factors	<ul style="list-style-type: none"> • Community needs • Challenges and social contribution • Acceptance and confidence • Price-quality relationship • Market power 	<ul style="list-style-type: none"> • Providing products with a suitable budget • Meet the market needs and social acceptance

3.3. E-services and environmental concerns

Results show the preliminary materials, governmental/institutional support, and operational costs are the most important requirements for the communities to start establishing small projects for producing personal protection materials (Table 2). Preliminary materials consist of all elements entered into production processes including manufacturing machines and preliminary elements (textiles, packaging machines, sustainable materials for PPE production) (Serman et al., 2021). Most of the responses indicated that preliminary materials are one of the requirements that may encounter a problem in availability during emergencies or lockdowns. The governmental-institutional support should include exemption from taxes, loans, e-services, publicity and announcement, marketing, financial assurance, and certification. About 44% of the responses presented marketing mechanisms as a common problem encountering small projects. Governments, NGOs, or any other third party should be involved in the

marketing process by validating e-marketing services or adopting a need-supply mechanism. Organizing the production of personal protective equipment can be done through a national production e-platform to minimize risks, exchange experiences and problems, complaints and feedback, resources management, and communications. The platform should also include a training gate and instruction records where the local community could communicate with experts and get access to all electronic materials. A high percentage of the responses (about 71%) suggested mobile stations for implementing training programs and this mechanism is feasible during emergencies and lockdowns. The stations may be equipped with all necessary educational tools and equipment for live experimentations. This suggestion was followed by e-platforms (about 60% of the responses) where people get access to "how it's made" records and explanation tutorials. Due to the variety of the educational background of the beneficiaries and internet status during emergencies, the e-platforms get less important than face-to-face training programs.

The responses have highlighted the environmental impacts of disposing of the personal protection equipment and the huge amount of generated solid wastes resulting from single-use PPE. There has been consensus that households have generated an additional huge amount of solid waste during lockdowns mainly plastic and foods originated wastes. 87% of the responses recommended the production of reusable PPE for lowering the rate of generated solid waste caused by personal protection behaviour (Alfarisi et al., 2022; Kumar et al.; 2021). Facemasks, hygiene containers, gloves, and other mechanical protection equipment can be even washable or reused before disposal (Fig. 4a). 13% of the responses minimize the importance of producing reusable PPE due to the social acceptance as many users prefer to use PPE for one time. However, two-thirds of the responses indicated that the pandemic and the community responses have impacted the environment in terms of plastic waste that they generate (Fig. 4b). The rest have neglected this impact because they compare the amount of PPE representing a low percentage in comparison with the other solid wastes generated due to the pandemic. Future studies should quantify the increase of each solid waste category in order to come out with recommended measures for future and similar contexts.

Table 2. Tools and materials should have been for the community to increase the chance of PPE production. Importance and magnitude demonstrate the purposes and the values of each tool/material

Tool/material	Importance	Magnitude
Preliminary material	•It is essential for forming PPE	Priority
Capital cost	•For startup and infrastructure •Sustain project growth	Priority
Packing tools	•Final product transport and market handling	Priority
Marketing platforms	•Easy access to costumers •E-pay enabling •Delivery tracking •Interactions with market needs •Activate e-services for the final product	Priority
Production lines or industrial tools	•Accelerate production •High-quality products •Perform complexities associated with production processes	Priority

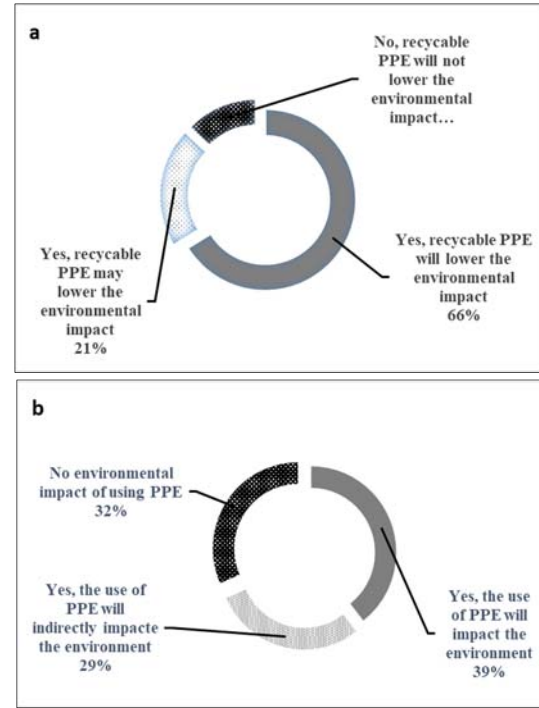


Fig. 4. The responses associated with the environmental impact of producing reusable PPE and single-use PPE are demonstrated by figure (a) and (b), respectively

Most of the responses (98%) have revealed the role of IoT in determining the PPE production strategies and mechanisms during emergencies. For instance, mobile apps can play a significant role in providing e-services to all stakeholders involved in the processes (Fig. 5) The apps should include services for delivery tracking systems, training materials, community needs, resources management, instructions, user info, and available items. E-services during emergencies is an essential need for providing services during emergencies as most of the respondents believe that similar pandemics may occur in the future. There was a suggestion to improve IoT tools and introduce them to the communities for further use in future similar contexts of the pandemic.

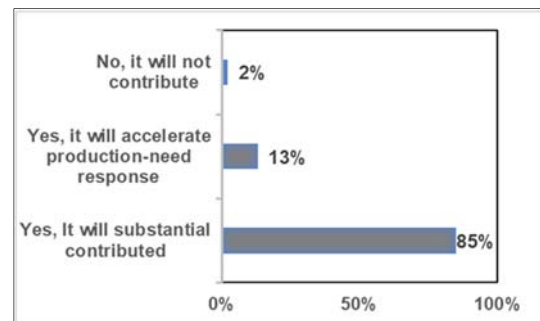


Fig. 5. The role of IoT in enhancing the production strategies and processes of PPE during emergencies

4. Conclusions

The economic and environmental benefits of producing PPE by local communities have been

presented. Many processes and procedures associated with PPE production have been addressed including e-services contribution during customer needs assessment to final product evaluation. This work introduced concepts and considerations for future works to build an integrated PPE production program with the essential preliminary considerations of the related e-services. Results have shown that producing PPE by local communities has positive environmental reflexes (86% of responses) and can enhance self-employment programs (73% of responses), especially during lockdowns as people may lose their jobs. PPE production by the local communities will overcome the problems with the supply chains and offer products based on the customer needs and purchasing power. IoT and other e-services have shown their importance for 98% of the respondents in enhancing the production processes of PPE and communication channels among stakeholders. Future works should discuss PPE production feasibility in terms of economy and societal readiness.

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