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Green operations management for sustainable development: An explicit analysis by using fuzzy best-worst method

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A B S T R A C T

With increasing concerns and challenges to climate change in recent years, green operations management (GOM) has gained significant attention from society for achieving sustainable growth. GOM is a set of practices that can be applied in production processes to produce goods with improved productivity and significantly reduced threats of carbon emission to the environment and Mother Nature. GOM mainly includes green manufacturing, green design, green logistics, and green purchases. In the paper, fuzzy best-worst method (FBWM) is used to determine the best and worst criteria affected by GOM practices. Thus, the paper attempts to explicitly analyze and highlight the significance of GOM in preserving the environment and manage the triple bottom line for achieving overall sustainable business operations.

1. Introduction

The operations management (OM) or non-green operations management (NGOM) practices is all about the management of the overall production of a product starting from areas like product designing, production processes to product logistics with an only objective to increase profits as shown in figure 1 (Groover, 2016). It aims to increase the quality of a product and the productivity of any organization to book higher profits without having much attention towards sustainability in business operations and the environment. Green Operations Management (GOM) also defines the same functions as NGOM along with sincere integrity and concerns towards the protection of the environment and Mother Nature and sustainability. GOM can be implemented in different sectors of an organization for example green manufacturing, green design, green purchases, and green logistics as portrayed in figure 2 (Groover, 2016). Green design is to create an innovative geometric design of products using environmentally-friendly work material (Watz & Hallstedt, 2020). The authors proposed a generalized model guide for companies to innovate and develop sustainable product designs to decrease carbon footprints. Green manufacturing is renovating manufacturing processes with no adverse impact on the environment (Zhang et al., 2019). The authors proposed a reference model for green manufacturing based on the industrial implementation of product life cycle and green index system which can be used as a reference model for companies to formulate their green manufacturing process plan.

Green logistics tend to decrease the ecological footprint during transportation without compromising the demands and needs of customers, Seroka & Ociepa, (2018). The authors reported the positive effect of green logistics on the circular economy. The green logistic and purchase practices reduce carbon footprints as well as support the waste management activities

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effectively Joshi & Rahman, (2015). It is imperative to explicitly analyze and highlight the significance of GOM practices in projects for preserving the environment and manage the triple bottom line for achieving overall sustainable business operations in comparison to the NGOM practices.

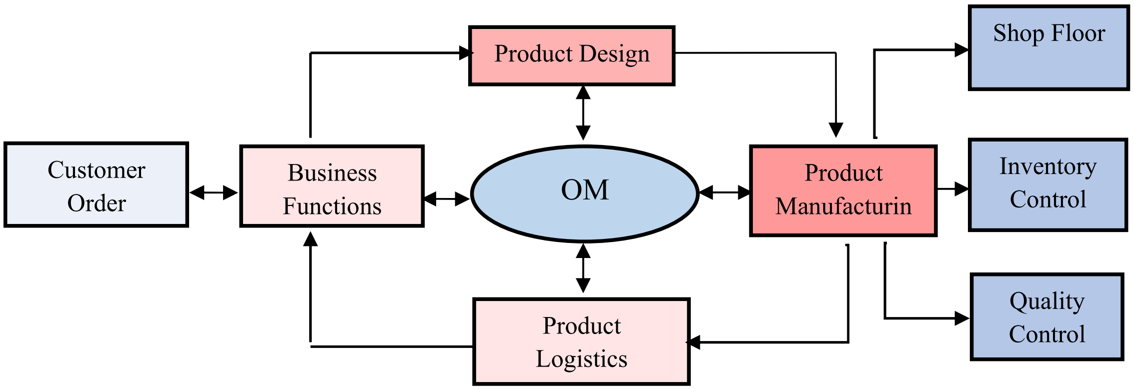

Fig. 1. Pictorial representation of NGOM cycle

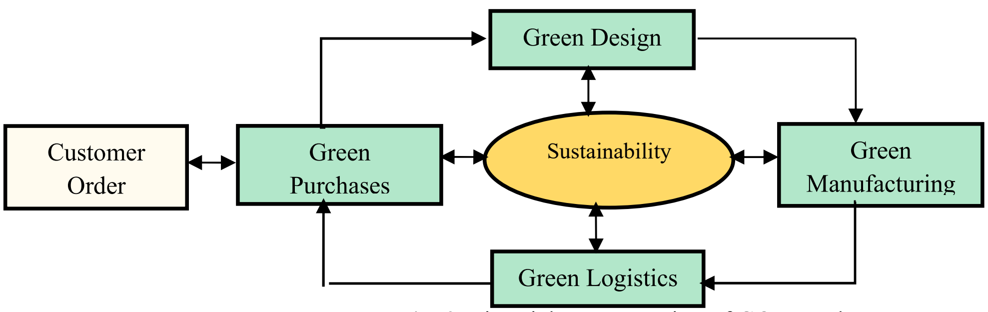

Fig. 2. Pictorial representation of GOM cycle

The paper comprises four more sections, the literature review, and research gap are mentioned in section 2. Section 3 describes the research methodology, and calculations. Results and discussions are carried out in section 4. In section 5, the paper is concluded along with possible future directions of the research. The research objectives of this study are enumerated as below.

i. Understanding the concept of GOM.
ii. Identifying economic and environmental benefits of GOM practices and finding the best and worst criteria affected using FBWM through a case study from the textile industry.
iii. Effect of GOM on the triple bottom line (sustainability).

2. Literature Review

Operations Management (OM) can trace its origin when it was first implemented in Henry Ford's assembly line in 1913 making history with the first mass production of cars (González & Vazquez, 2017). OM helps an organization to manage its resources like material, structure, funds, and labor effectively which improves the overall productivity and profitability. It also gives a competitive advantage to an organization as processes become smooth and customer satisfaction increases.

However, in the past few decades, the human lifestyle has undergone a significant change and it has put the environment under huge threat. Environmental concerns like non-renewable resource depletion; deforestation, global warming, and pollution are disturbing the ecosystem's balance. The average global temperature on earth has risen by 1.5 °C and will continue to 2 °C (Djalante, 2019). The river GANGES is considered as a lifeline to India and worshiped as a deity by many Indians is under major threat due to the irresponsible behavior of industries towards their waste disposing practices, and unplanned industrialization along the river. All these factors have caused flow path alteration and water pollution in the river Ganga and its associated water bodies (Singh & Singh, 2019). Therefore, to protect the environment and humankind, companies are changing their viewpoint and shifting from OM towards GOM to achieve sustainable development (Chawla et al., 2018; Chawla et al., 2021). Sustainable development is derived from the word Sustainability, it is defined as the effective utilization of resources so that present, as well as future generation demands, are fulfilled without affecting the environment and resources adversely. The United Nations (UN) aims to achieve sustainability by the year 2030 through 17 sustainable development goals (SDGs). Sustainable development not only will reduce poverty, inequality, and economic gaps between different strata of society but also preserve Mother Nature.

2.1 Green Operations Management

In this section, some of the major key factors contributing to environmental conservation are reported from the literature. Additionally, the significance and contributions of GOM practices for reducing various environmental concerns in the form of carbon footprints to preserve nature are described. One of the major environmental concerns is the emission of carbon dioxide. It is a gaseous pollutant that adversely affects the environment. The major source of carbon dioxide emission is the burning of non-renewable resources. Expanding industrialization and urbanization have given rise to another major concern of exhausting non-renewable resources. Non-renewable resources take millions to years form but are getting depleted at an exponential rate. The current scenario is forcing companies to switch to other alternatives of resources that are renewable and eco-friendly. Mosiño (2012) compared both renewable and non-renewable energy materials and found that shifting from non-renewable to renewable energy resources depends on many factors such as energy demand, cost, local renewable resource availability, and government policies. Adams and Nsiah (2019) conducted a study and found that Carbon emissions can be attributed to both renewable and nonrenewable energy consumptions. However, nonrenewable energy consumption yields more carbon emissions in comparison to non-renewable energy consumptions. Wagh and Kulkarni (2018) reviewed various renewable energy integration models and highlighted the development of smart grids, decentralized energy planning, and energy management practices. Energy conservation is also equally important, saving energy leads to a reduction in emission of carbon dioxide, greenhouse gasses, and consumption of non-renewable resources. Fernando et al., (2018) studied energy conservation on a renewable energy supply chain and found that conserving energy requires knowledge of energy flow, framing an energy management strategy, and regular audits to monitor the progress. He et al. (2016) reported that instead of running a conveyor belt at a constant speed continuously, regulating the speed according to the load decreased the electricity expenditure by 10%, leading to a significant reduction in carbon dioxide emission. Thus, a small change can have drastic effects on preserving the environment. Chel and Kaushik (2018) discussed the concept of energy-saving in buildings. Using solar panels to provide electricity, using eco-friendly material for building construction are some of the areas that are now being considered in modern construction. Urbanization has also put biodiversity under threat, and it needs to be conserved. Opoku (2019) studied the relationship between the built environment, sustainable development goals (SDGs), and biodiversity. Authors observed that the built environment is responsible for the loss of biodiversity by disturbing the natural environment, but, the damage to biodiversity can be repaired by integration of the biodiversity in the development projects. Reale et al. (2019) compared the corporate sustainability index (CSI) of seven different companies and found many companies fail to achieve sustainable management policies due to a lack of awareness and support from the government. Therefore, to conserve and protect biodiversity at the world level, a widespread awareness towards sustainable environment development and protection is to be carried out for governments and common people.

Global warming is also observed as one of the most prominent threats to nature, the rise in average global temperature and sea levels have imposed a threat to the lives of both animal and plant kingdoms. Acar and Dincer (2020) investigated the possibility of using hydrogen as fuel in cars to reduce the effects of global warming. The author's study showed that hydrogen is one of the best solutions for sustainable energy generation. It is clean, convenient, safe, and reliable. The hydrogen can be produced more immaculately with zero or minimal emissions (Acar & Dincer, 2020). Yuksel (2012) reviewed the benefits of using hydroelectric technology for power generation in controlling the global warming effect on the planet. Hydropower remains the best alternative for fossil fuels in power generation provided its environmental-friendly benefits of no atmospheric pollutants and greenhouse emission.

A logistic plays a significant role in managing the supply chain in an organization Yazdani (2014). Reduction in the distance not only helps in reducing carbon emissions but also saves transportation time enormously. It has a vital impact on the preservation of the environment and time saving gives a huge profit in the business cycle. The reverse logistics application can reduce distance and travel time. The reverse logistics intend to complete the entire loop of the logistics cycle starting from delivery of the product to the customer to returning the used product to services or recycling. Shi et al., (2019) proposed a reverse logistic model and developed a sustainable transportation system for trucking companies and reported that the application of reverse logistics minimizes fuel consumption and saves labor costs. Agarwal and Singh (2019) correlated the benefits of reverse logistics with the triple bottom line and mentioned that reverse logistics plays a vital role in a circular economy implementation resulting in the better overall management of the triple bottom line. The protection of the environment is highly significant for sustainable development and progress Chawla et al. (2018). The untreated waste, open dumping practices have given rise to many health hazards and pollution. Pujara et al. (2019) analyzed the waste disposal scenario in India and found that converting waste to a form of energy is a way to deal with solid waste management issues. The authors proposed bio-composting and the use of biogas in electricity production and mentioned that reuse-derived fuel from combustible municipal waste is an effective and efficient solution to the waste management problem. Heidari et al. (2019) proposed TOPSIS methodology to analyze solid waste management techniques namely anaerobic digestion in which organic waste is converted into fuel and sanitary land-filling where waste is first segregated before its disposal. Varshney et al. (2020) did a case study on lead-acid batteries and found that the lead available in the lead-acid batteries can be 100% recycled. Authors investigated that lead-acid batteries emit less carbon dioxide and can be reused in various industries as raw materials. Solis and Silveria (2020) analyzed different chemical recycling technologies namely thermal cracking, catalytic cracking, hydrocracking, and pyrolysis, and reported that recycling household plastic waste reduces greenhouse gasses emission significantly. Goyal et al. (2019) found that quality management plays a major role in sustainable manufacturing as it determines the end of the product cycle. Authors mentioned that the defective products end up in two ways, either disposed of in waste or recycled/reworked depending on the severity of defects. Bastas and Liyanage (2019) studied the integrated approach of supply chain management, quality management, and sustainability. Authors reported that the supply chain and quality directly influence the sustainability of a product. And found that an integrated approach towards supply chain management, quality management, and sustainability has a huge potential for achieving sustainable development. Zore et al. (2017) studied the relationship between the economic, social, and sustainable profit from a company's and government's point of view. The authors found that sustainable profits can be increased with the equal involvement of companies and the government. Authors reported that the companies and government must be willing to frame policies and take decisions for economic growth and the benefit of people and the environment.

From the literature review, it is evident that the GOM has great research potential and not much has been practically implemented in this area. Its implementation in business operations will be highly beneficial for sustainable business cycles with substantial profits without hampering the basic environment structure and nature's life cycle. The FBWM is applied to find the best and worst criteria affected by using the GOM practices and the interrelation of all other criteria. Hence, this manuscript is directed towards explicitly analyzing and investigating the significance of GOM practices in the preservation of the environment and management of the triple bottom line (TBL) in a business process. Various parameters that lead to the conservation of nature and their effect on TBL as discussed in the literature review are summarized in Table 1. Each parameter is given an acronym which will later help in evaluation and analysis using the FBWM.

Table 1
Parameters leading to Conservation of Nature

S.No.	Effect on TBL	Advantages of GOM	Acronym	References
1.	Sustainability	Preservation of biodiversity in nature	PB	Opoku (2019); Reale et al., (2019)
2.	Climatic	Carbon emission reduction	CER	Adams & Nsiah, 2019; He et al., (2016); Aggarwal & Chawla, (2021)
3.	Economic	Improvement in quality	IQ	Goyal et al., (2019); Bastas & Liyanage (2019)
4.	Economic	Conservation of energy	CE	Fernando et al., (2018); Chel & Kaushik (2017)
5.	Climatic	Minimisation in distance	MD	Shi et al., (2019); Agarwal & Singh (2019); Chawla et al., (2019a, 2019b, 2020); Wichapa & Khokhajaikiat (2018)
6.	Sustainability	Management of waste	MW	Pujara et al., (2019);Heidari et al., (2019)
7.	Economic	Optimization in cost	OC	Zore et al., (2018); Jain & Raj (2021)
8.	Sustainability	Recycling	RC	Varshney et al., (2020); Solis & Silveria (2020)
9.	Sustainability	Reduction in non-renewable resources	RNRS	Mosiño (2012); Wagh & Kulkarni (2018)
10.	Climatic	Impact on global warming	IGW	Acar & Dincer (2020); Yuksel (2012)

3. Research Methodology

The FBWM is a multi-criteria decision-making mathematical tool. An MCDM tool works by identifying the goal, choosing the parameters to analyze the goal, and the alternatives or paths are taken to reach the goal. Numerical data is used which is collected in form of surveys to solve the problem. A major textile manufacturing company is taken as a case study for this research. Section 3.1 discusses the company processes and various initiatives it took towards GOM.

3.1 Case Study

Clothes are one of the basic requirements of humans. The production and sale of clothes are one of the oldest businesses in the human race. The manufacturing of clothes involves a lot of processes. The process starts by designing, selecting raw material, a manufacturing process that includes knitting, weaving, finishing, embroidery, printing, etc. It is then followed by packaging and distribution and finally disposing of waste clothes. All these processes have a direct or indirect impact on the environment.

The clothes made from synthetic fabrics as raw materials, which now dominate the textile industry are processed with heavy chemicals which deplete the environment. The fabric treatment involves bleaching, straightening, shrink resistance, stain, and odor resistance. Most of the fabric treatment is carried out by using toxic chemicals and water. These chemicals alter the pH of water which is later released into water bodies causing water pollution. These fabrics while wearing emit effluent heat which gets absorbed by human skin causing skin-related problems (Eryuruk, 2012). With an increasing rate of consumers and awareness to protect the environment, the textile companies are trying to promote environmentally-friendly fabric. In recent years, a lot of emphasis is given to using organic textiles for manufacturing.

The clothing production industry tried implementing GOM practices in their processes. The first being managing waste. There are two types of waste: pre-consumer and post-consumer. Pre-consumer waste is the by-product produced during the manufacturing process. That material can be recycled into new raw material. Post-consumer is the waste generated when the textile is worn out, outgrown, or damaged. The company segregated the by-product waste by color and type and then sent them into shredding and re-spinning where they are spun into new yarn and used again for manufacturing. This not only helped in reducing the burden on the landfills but also in the reduction of emission of toxic gasses like methane and carbon dioxide. Post-consumer waste generated was used for other purposes such as cleaning etc. Second, introducing reverse logistics. The reverse logistics concept involves planning and implementing the flow of material in a way that the point of origin and finish completes a loop. This involves green procurement which is the management of material from ordering to dispatch so that the least resources are used, and material is delivered on time with the best cost-optimized. Data was collected by forming a team involving experienced managers, experts of that company. A questionnaire was prepared which involved questions related to the company's existing operations and the initiatives taken towards green operations. The data collected is used for analysis between GOM and NGOM practices further in the paper.

3.2 The Fuzzy Best Worst method

The best-worst method (BWM) is a multi-criteria decision-making tool, proposed by Rezaei, (2015). The proposed method selects the best and worst criteria and compares them with other criteria by calculating weights Bonyadi et al., (2019). It is a pairwise comparison matrix method. The major benefit of this method is that only two comparison matrices are formed, one for best and another for worst criteria. This helps to solve the problem in a structured way (Rezai, 2016). It is used in many real-world problems in the field of business, health, and agriculture. Fuzzy Best-Worst Method (FBWM) is an advanced version of BWM and is based on triangular fuzzy numbers. The benefit of FBWM compared to BWM is that it includes fractions as well which gives more consistent results (Guo & Zhao, 2017). In the paper, to apply the FBWM, the criteria are sub-divided into sub-groups to ease the calculation part. The sub-groups are Climatic (CER, MD, IGW), Sustainability (PB, MW, RC, RNRS), and Economic (IQ, CE, OC). The criteria are sub-grouped representing their direct relation with their main-group name as explained in section 2, literature review.

3.5 Calculation using FBWM

The calculation is carried out in the following steps-

Step 1- Assumption of best and worst criterion

The best and worst criterion is assumed out of the taken group at a time. From sub-group Climatic, CER and IGW; from sub-group Sustainability, MW and RNRS; from sub-group Economic, IQ and OC are assumed as best and worst criteria, respectively. And among the sub-groups sustainability and economic are assumed as the best and worst criteria, respectively.

Step 2- Scaling of criteria

All the criteria in their respective sub-groups are scaled according to the best and worst criteria of that sub-group. Thereafter, groups are scaled to each other. Scaling is carried out using Fuzzy BWM Scale (Table 2) Moslem et al. (2020).

Table 2
Fuzzy BWM Scale

Intensity	BWM Scale	Fuzzy BWM Scale
		Triangular Fuzzy Numbers (TFNs)
Equally Important	1	(1,1,1)
Weakly Important	1	(1/2,1,3/2)
Fairly Important	2	(3/2,2,5/2)
Very Important	3	(5/2,3,7/2)
Absolutely imporatnt	4	(7/2,4,9/2)

Step 3- Calculation of Fuzzy and Normalized weights

After scaling, fuzzy weights are calculated by solving the following equations assuming-

$\xi^* = (k^*, k^*, k^*)$

min ξ^*

subject to

$$\left|\frac{(l_b, m_b, u_b)}{(l_j, m_j, u_j)} - (l_{bj}, m_{bj}, u_{bj})\right| \leq (k^*, k^*, k^*)$$

$$\left|\frac{(l_j, m_j, u_j)}{(l_w, m_w, u_w)} - (l_{jw}, m_{jw}, u_{jw})\right| \leq (k^*, k^*, k^*)$$

$\sum (\widetilde{W}_j) = 1$

$u_j > m_j > l_j \geq 0; for\ all\ j$

where,

$l_b, m_b, u_{b=}$ *Fuzzy Weight of best criteria for lower, middle, upper limit respectively*

$l_w, m_w, u_{w=}$ *Fuzzy Weight of worst criteria for lower, middle, upper limit respectively*

$l_j, m_j, u_{j=}$ *Fuzzy Weight of criteria for lower, middle, upper limit respectively*

$l_{bj}, m_{bj}, u_{bj=}$ *Fuzzy Preference score of best criteria w.r.t other criteria in lower, middle, upper limit respectively*

$l_{bjw}, m_{jw}, u_{jw=}$ *Fuzzy Preference score of best criteria w.r.t other criteria in lower, middle, upper limit respectively*

$\widetilde{W}_j =$ *Normalized Weight of criteria*

After calculation of Fuzzy weights, normalized weights are calculated by the formula,

$$\widetilde{W}_j = \left(\frac{l_j + 4m_j + u_j}{6}\right)$$

Step 4- Calculation of consistency

Consistency is represented by Ksi*. Its formula is as shown below

$$\text{Consistency Ratio}\left(Ksi^*\right) = \left(\frac{\xi^*}{\text{Consistency Index}}\right)$$

The consistency index value for all variables is shown in Table 3 (Moslem et al., 2020).

Table 3
Consistency Index of FBWM

Variables	(1,1,1)	(1/2,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(7/2,4,9/2)
CI	3.00	3.80	5.29	6.69	8.04

The best-worst values and value of fuzzy and normalized weight for the sub-groups namely, climatic, sustainability, and economics respectively are shown in Tables 4, 5, and 6. To calculate and identify the best – worst criteria more precisely, the ten factors namely PB, CER, IQ, CE, MD, MW, OC, RC, RNRS, and IGW, are sub-grouped into three categories namely climatic, sustainability, and economics respectively.

Table 4
Best-Worst value for the Sub-group 1 (Climatic)

	CER	MD	IGW
Best CER	(1,1,1)	(7/2,4,9/2)	(3/2,2,5/2)
Worst IGW	(3/2,2,5/2)	(5/2,3,7/2)	(1,1,1)
Fuzzy Weights	(0.11, 0.64, 0.96)	(0.08, 0.13, 0.72)	(0.05, 0.12, 0.40)
Normalized Weights	0.61	0.22	0.16

Table 5
Best-Worst value for the Sub-group 2 (Sustainability)

	PB	MW	RC	RNRS
Best MW	(5/2,3,7/2)	(1,1,1)	(7/2,4,9/2)	(7/2,4,9/2)
Worst RNRS	(7/2,4,9/2)	(7/2,4,9/2)	(7/2,4,9/2)	(1,1,1)
Fuzzy Weights	(0.08,0.13,0.72)	(0.4,0.45,0.84)	(0.05,0.10,0.56)	(0.02,0.06,0.22)
Normalized Weights	0.22	0.51	0.17	0.08

Table 6
Best-Worst value for the Sub-group 3 (Economic)

	IQ	CE	OC
Best IQ	(1,1,1)	(5/2,3,7/2)	(7/2,4,9/2)
Worst OC	(7/2,4,9/2)	(1/2,1,3/2)	(1,1,1)
Fuzzy Weights	(0.12, 0.66, 1.02)	(0.04, 0.18, 0.30)	(0.02, 0.11, 0.15)
Normalized Weights	0.63	0.18	0.10

The value of global weights for the three sub-groups namely climate, sustainability, and economic is reported in Table 7.

Table 7
Value of global weights

	Climatic	Sustainability	Economic
Best Sustainability	(7/2,4,9/2)	(1,1,1)	(1/2,1,3/2)
Worst Economic	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)
Fuzzy Weights	(0.10, 0.17, 0.89)	(0.25, 0.56, 0.75)	(0.04, 0.20, 0.66)
Normalized Weights	0.28	0.54	0.25

Step 5- Calculation of weights for each criterion

The individual weight of factors is acquired by multiplying the normalized weight of each criterion to their respective global weight. Table 8 shows the weight of each criterion and figure 3 shows the bar graph presentation of the weight of each criterion.

Table 8
Weights of criteria

S. No.	Factors	Calculation of Weights	Weights
1.	PB	0.61 × 0.28	0.171
2.	CER	0.22 × 0.28	0.061
3.	IQ	0.16 × 0.28	0.044
4.	CE	0.63 × 0.25	0.157
5.	MD	0.18 × 0.25	0.045
6.	MW	0.10 × 0.25	0.025
7.	OC	0.22 × 0.54	0.118
8.	RC	0.51 × 0.54	0.275
9.	RNRS	0.17 × 0.54	0.092
10.	IGW	0.08 × 0.54	0.043
Sum			1

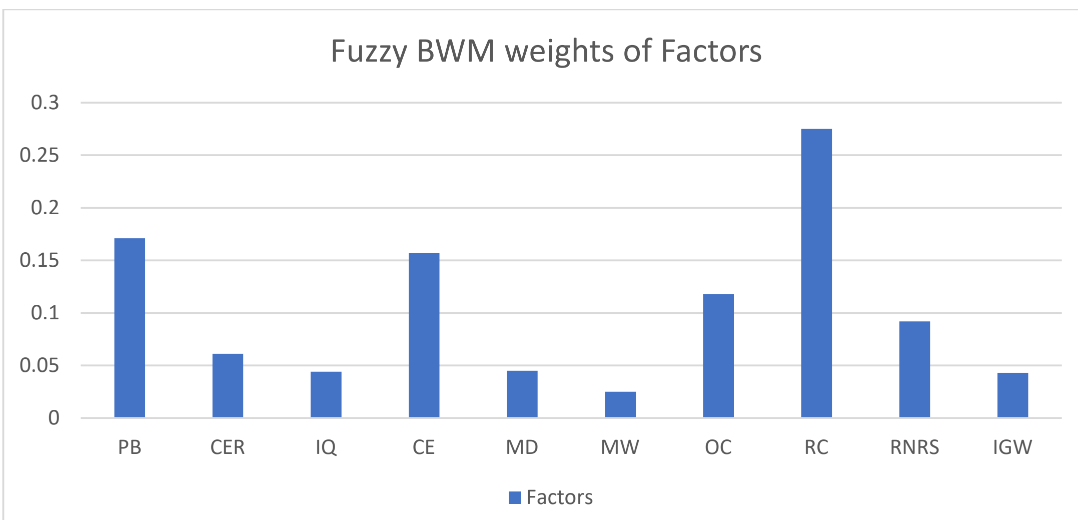

Fig. 3. Weight of all criteria by Fuzzy Best-Worst method

Thus, from Table 8 and Fig. 3, the best and worst criteria affected by GOM are MW and OC respectively as also shown in Table 9.

Table 9
Fuzzy Best and Worst Criteria

Best Criteria	MW	0.275
Worst Criteria	OC	0.025

4. Results and Discussion

The result from the FBWM shows that the best and worst criteria affected by GOM practices are MW (0.0275) and OC (0.025) respectively. From the literature review, it is found a lot of waste of any kind is produced every year and this waste has a huge potential to be recycled and used as a source of fuel for various industries. Thus, MW came as the best-affected factor of GOM practices. Since implementing GOM practices requires a change in technology which is not cost-effective in the initial stage. Thus, OC came as the worst affected factor of GOM practice. But considering it a one-time investment GOM has huge benefits to an organization in the long run. The global weight of criteria MW and OC in FBWM is 0.275 and 0.025 respectively as weights are compared with each other within the GOM domain.

From the research mentioned in the literature and the analysis carried out in the paper, two points were observed to be common. First, the government needs to support sustainable development and reframe its policies considering rising environmental concerns as a serious threat. The protection of Mother Nature should be given priority in any decision-making process. Second, awareness should be spread among people regarding environmental concerns and encouragement should be given towards implementing GOM practices.

5. Conclusion and future work

A new concept of Green operations management (GOM) comprising green manufacturing, green design, green purchases, and green logistics practices is explored in the paper. The main aim of GOM is to achieve sustainability and productivity simultaneously. Various factors that affect the conservation of the environment were discussed and identified as PB, CER, IQ, CE, MD, MW, OC, RC, RNRS, and IGW. A case study of an Indian textile manufacturing company is presented for analysis of GOM practices using FBWM. The results from the application of the FBWM indicate the best and worst criteria in the application of GOM practices. It is found that the best and worst criterion affected by GOM practices is MW and OC with their weights as 0.0275 and 0.025, respectively. In the future, the results can be optimized by using modeled evolutionary algorithms on the formulated problems related to GOM practices. As the technology is shifting towards the concept of Industry 4.0 considered as a reference to the fourth industrial revolution. The conventional manufacturing processes are getting replaced by automation and robotic technology. As automation will take manufacturing a step further, GOM practices implementation seems to have a huge scope. It is high time to think and apply sustainable ideas to save and protect the environment alongside the development and growth of society. This study can assist the private sector and public sector to reconsider and redesign the policies and strategies by the holistic inclusion of GOM practices at each level.

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