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Contents

FORMING THE AREA OF UNACCEPTABLE VALUES OF THE PARAMETERS OF VESSELS' MOVEMENT FOR THE VESSELS' DIVERGENCE AT REMOTE CONTROL PROCESS

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Highlight
Safety of the vessels' divergence process can be ensured using the method of forming the unacceptable values areas of vessels' motion parameters.

Abstract
Navigation traffic and the danger of collision are steadily increasing. Features of navigation in narrow corridors (water, air, etc.) require the development of modern methods for assessing the situation of convergence and the choice of maneuvering divergence of vessels. A method is proposed for forming the area of inadmissible values of the parameters of the movement of any vehicles (including marine) with remote control of the process of their divergence. Situations are considered when a collision of sea vessels can be avoided only by changing the speed in case such vessels cannot change course. The proposed method can be generalized to any environment of navigation.

Keywords
navigation safety; collision avoidance; divergence maneuver; area of unacceptable values of vessels' movement parameters.

Introduction
In the modern era, the intensity of both crewed and unmanned navigation is steadily increasing [1]. Inland shipping is an important pillar of the European transport system. According to statistics, about 20–30 collisions per year result in damage to waterway infrastructure, damage to vessels, or even injury to people [2]. In this regard, it is relevant to increase the requirements for the accuracy of maneuvering vessels using both coastal and onboard equipment.
The frames for the safety of navigation are indicated in the European Code for Inland Waterways CEVNI EG/2021/11 [3]. According to Article 6.16 of the said Code, the vessel's maneuvers may be carried out safely in such a way that other vessels are not forced to suddenly change their course or speed. When simulating vessel maneuvers, it must be considered that the vessel performing the maneuver must give priority to any vessel going upstream. In addition, when simulating a speed reduction, it should not be lower than the speed necessary for the safe management of the vessel before entering the port, near ships that are moored to the

shore and in other situations provided for within the scope of Article 6.20 of the CEVNI Code. At the same time, the safe speed must be determined considering the deterioration of the visibility restriction, the presence and movement of other vessels, as well as local conditions by Article 6.30 of the CEVNI Code. When maneuvering, vessels should, as far as possible, clear the fairway and pass to the port.

In addition, in the process of determining the parameters of the safe divergence of vessels, it is very important to exclude the influence of the human factor on the speed and quality of the choice of courses during the maneuver for vessels [4]. For this, the possibilities of computer simulation modeling are best suited [5].

The avoiding of collisions between maritime transport provides in accordance with the international protocol COLREGs [6]. In considering scenarios of the vehicles' (including maritime) divergence process, researchers mainly use vehicle trajectory data [7]. Moreover, when choosing their course, the vessels must coordinate their decisions with neighboring vessels. In this case, vessels can only change their course, while maintaining their speed, taking into account the parameters of the vessels as a whole [8]. However, taking into account the possibilities of solving more complex future situations, it is necessary to consider the possibility of changing the speed of the vessel as well [9]. One of the criteria in the development of collision avoidance algorithms is the observance of the minimum distance between vessels following each other [10]. Consideration of this task as a multi-criterion is necessary to avoid the collision of vessels with other vehicles (for example, mobile robots or drones), which are under remote control [11]. In this case, maneuvers can be performed as a change of the course for both vessels, a change in their speed, as well as a change of the course of one vessel, and a change of the speed of the other vessel [12].

To control the navigation process and control the movement of dangerously approaching vessels, they are equipped with an onboard radar station supported by Vessel Traffic Service (VTS). VTS collects up to 560 million location records [13] since VTS works not only with navigation but also with bathymetric and meteorology information [14]. VTS can use automatic identification system (AIS) data, local radar data, meteorological data, and video camera data [15,16].

For a comprehensive operational analysis of the actual situation on the movement of vessels using the obtained data, it is very important to construct a graphical display of the area of unacceptable values of the parameters of the movement of vessels. Then, based on visual analysis, it is easier to understand the trend of vessels' movement in the navigable waterway in real-time [17,18]. Integrated information can be comprehensively and realistically interpreted and effectively used to prevent a collision. However, to use such data, anomalies must be excluded from them, for example, using the K-means-based anomaly detection method [19] or rearrangement task [20].

After obtaining data without anomalies, they are used to analyze and predict trends in vessel traffic, both on the remote control and the man steering. During analyzing navigational measurements, mixed probability distribution laws are effectively applied to random errors [21,22]. Also, attention should be paid to the fact that the means of control and management of navigation, which are based on radio technology, may not work in conditions of numerous complex (noise-like) signals, which are close to "white noise". To reduce the effect of noise and interference, one can use, for example, the algorithm ASBD-RC [23] or CCRP [24].

The work of such systems is especially difficult for the safety of sailing in coastal sea areas in a bay and a port, so-called "narrow/compressed areas" with particularly heavy traffic [25]. With this trend in the near future, all shipping routes will be laid in narrow areas [26].

To ensure the safe divergence of vessels, it is necessary to develop modern means of preventing collisions of vessels, which use methods of safe divergence of two or more vessels. In this case, it is necessary to consider both autonomous and remote control to prevent collisions. The forming of the area of unacceptable values of the vessels' movement parameters is also promising.

Therefore, the analysis of dangerous convergence of vessels and the definition of the area of unacceptable values of the parameters of the movement of vessels for their differences over time is becoming increasingly important.

Methods

To solve the problem of collisions between vessels, it is necessary, first of all, to simulate the forms of interaction between vessels in case of disappearance and the procedure for calculating safe maneuvers. The problem of the absence of vessels collisions can be solved by using the flexible food travel method [27]. To determine the individual and used trajectory of the situation on the vessels, one can use the methods of applied dynamic programming with the constraints of the neural state in rare navigational observations at sea [28]. With this degree of discreteness of calculations, the headquarters are distributed along the vessels' route.

To ensure maximum safety of vessels during divergence, it is necessary to determine as accurately as possible the coordinates of each of the vessels participating in the divergence process. In this case, a good result can be obtained by the vessel's observed coordinates estimation using the mixed laws of distribution errors of the first and second type for lines of position (LOP) [29].

Formalization of the vessels' interaction in case of divergence can be carried out by methods of differential games. In this case, an approximation mathematical model as a triple linear programming problem allows synthesizing a safe trajectory of a vessel's movement as a multi-stage solution process [30].
Multistage is also introduced into the trajectory clustering method for reliable clustering of AIS trajectories. Dynamic Time Warping (DTW-algorithm) can be used to measure distances between trajectories. It allows describing vessels' interactions in case of divergence [31]. This method is competitive with traditional clustering methods such as spectral clustering and fast affinity propagation.
In some cases, the study of the safety of navigation can be carried out using Bayesian networks for the synthesis of a priori information and sample information. Through establishing the Bayesian network model, the prevention of ship grounding, collision, and fire may be achieved [32]. Using Bayesian networks to study the safety of navigation is not only easy for understanding, but also has a clear causal relationship. It can be easily improved and updated in later work.
The idea of generating evasive trajectories or optimizing the trajectories of all ships involved is not new [33]. Such trajectories should not only be collision-free, but they should also additionally guarantee that an evasive maneuver can be performed at any time.
The analyzed methods of vessel divergence are mainly used for locally independent control. Recently, methods of remote control of the vessel divergence process are being developed, which are addressed to the operators of the Vessel Traffic Services (VTS). Insufficient attention has been paid to the accounting and use of such modern methods.
In the presented work, the determination of the divergence strategy of the vessels is carried out using the developed method of forming the area of unacceptable values of the vessels' motion parameters during their remote control.

Results and discussion

Full (remote) control of the vessels' divergence process is carried out by an external manager who forms a strategy of vessels' divergence. He observes the current situation and, in the presence of situational indignation, compensates for it by a joint maneuver of divergence. Such a manager can be both a VTS and a Vessel Traffic Management Systems (VTMS). VTMS is installed on each of the vessels and has the same capabilities compared to VTS. This approach solves the problem of collective compensation of situational disturbances and implements the individual strategy obtained as a result of the decision.
In general, a group of two vessels will be called an "elementary group". Then it is advisable to formalize it using the following mathematical model. Suppose at the initial moment of time, the relative position of the vessels is characterized by the parameters α_o and D_o. At the same time, many possible combinations of their motion parameters (as components of the control vector) can be described by a four-dimensional space of motion parameters K_1, V_1, K_2, V_2, which we will call the space of true motion. Likewise, the space of relative motion is a two-dimensional space of the motion relative parameters – course K_{ot} and speed V_{ot}. The relative position, that is, the values of the bearing α and the distance D, is invariant for both spaces.
Traditionally, the maximum permissible rapprochement distance $D_d$does not depend on the relative position of the elementary vessels group and is assumed to be unchanged in magnitude for the rapprochement situation that has taken place. This means that the vessel safe domain is circular and is set in the relative motion space.
The boundary between the subset of safe situations S_s and the subset of situations S_ω leading to dangerous rapprochement is determined by the equality of the distances of the shortest vessels 'rapprochement and the maximum allowable rapprochement, that is, $D_{\min} = D_d$, provided that the vessels approach each other ($\dot{D} < 0$). The values $D_{\min}$ and $\dot{D}$ are defined by initial relative position and relative motion parameters:

(1)
$$D_{\min} = |D\, sin(K_{ot} - \alpha)|$$
$$\dot{D} = -V_{ot}\cos(\alpha - K_{ot})$$

Since when vessels' rapprochement $\dot{D} < 0$, then $0 \le (\alpha - K_{ot}) < \pi/2$.
As follows from the above expressions for $D_{\min}$ and $\dot{D}$, the boundary between subsets of situations S_s and S_ω defined by one point (K_{otg},V_{otg}) in the relative motion space. This point corresponds to the boundary in the true movement space, depending on the parameters of the vessels movement that satisfy the relationship:

(2)
$$D_d = F_{rt}(K_1, V_1, K_2, V_2)$$

where F_{rt} – mapping from relative motion space to true motion space.

If the boundary (2) of a four-dimensional space is projected onto one of its planes, then it is possible to obtain the boundaries of two-dimensional regions of unacceptable movement parameters of a vessels' elementary group. The axes of such planes are the movement parameters of the different vessels in an elementary group, i.e., $K_1 \times K_2$, $V_1 \times V_2$ or $K_1 \times V_2$,

As a result, one can obtain an expression for the boundary of two-dimensional areas of unacceptable movement parameters of a vessels' elementary group:

(3) $$V_1(\sin K_1 \cos \gamma - \cos K_1 \sin \gamma) = V_2(\sin K_2 \cos \gamma - \cos K_2 \sin \gamma)$$

where $\gamma = \alpha \pm \arcsin\left(\frac{D_d}{D}\right)$.

The resulting equation for a given value of γ connects the values of vessel traffic parameters K_1, V_1, K_2 and V_2, at which the boundary is reached in the space of true motion between the sets of dangerous and permissible situations during vessels' rapprochement. In the process, γ is determined by the initial relative position of the ships. Thus, the equality $\min D = D_d$. Therefore, if in the space of true motion, the boundary (3) is projected on the plane, then using equation (3) it is possible to obtain the dependence between the parameters P_x and P_y (4). In this case, the axes of the agreed planes are the parameters of the movement of different vessels. In this case, out of four vessel traffic parameters two parameters P_a and P_b can be fixed, and consider the remaining two parameters P_x and P_y as variables.

(4) $$P_y = f(\gamma, P_a, P_b, P_x)$$

The relationship between the parameters P_x and P_y in (4) represents a curve on the plane $P_x \times P_y$, which is the boundary of the area Ω of unacceptable values of the parameters P_x and P_y.
For points $(\rho_x, \rho_y) \in \Omega$ vessels' rapprochement is dangerous. If the points (ρ_x, ρ_y) are on the boundary Ω or outside it, then the rapprochement is safe, and the situation of vessels' rapprochement is acceptable.
With a free water area for maneuvering, the most preferable is the divergence maneuver by changing the course. Therefore, courses of approaching vessels K_1 and K_2 are selected as variable parameters P_x and P_y. In this case, $P_x = K_2$ and $P_y = K_1$, parameters V_1 and V_2 are unchanged. In this case, expression (4) describes the boundary of the area of unacceptable course values for an elementary group of vessels and takes the following form:

(5) $$K_1 = \gamma + \arcsin(\rho[\sin(K_2 - \gamma)]),$$

where $\rho = \frac{V_2}{V_1}$ and $V_1 \geq V_2$.
Since $\rho < 1$, the course K_2 takes all values from 0 to 2π.

Figure 1 shows the area of unacceptable course values S_{Dij} for V_1=20 knots, V_2=15 knots.
Thus, having an area of unacceptable values of the courses S_"Dij" for two ships, you can choose their safe avoidance courses belonging to the boundary of the area S_"Dij". The selected courses of avoidance provide a divergence at a distance equal to the maximum allowable distance of the vessels' rapprochement.
In narrow waters, there are situations in which vessels cannot change their course due to dangerous rapprochement. Therefore, their collision can be prevented only by changing the speeds. In this case, the vessel speeds are selected as variables, i.e., $P_x = V_2$ and $P_y = V_1$, and the vessel courses K_1 and K_2 are unchanged. With this formulation of the problem, an area of unacceptable values of the speeds of an elementary vessels' group is formed.

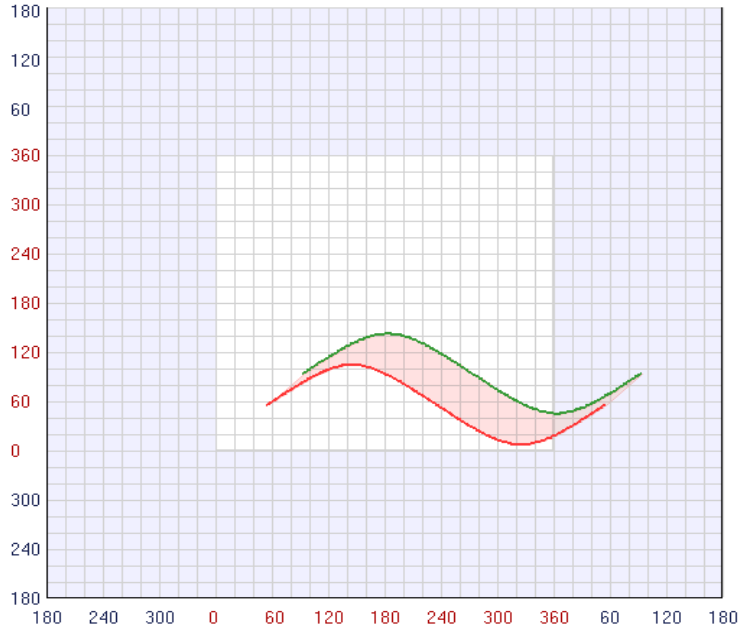

Figure 1. The area S_{Dij} of the courses K_1 and K_2 for $V_2 < V_1$. *Source: Author's.*

From expression (3), an equation can be written for the boundaries of the dangerous area of speeds, including for the upper boundary:

(6) $$V_1^* = V_2 \frac{\sin(K_2 - \gamma^*)}{\sin(K_1 - \gamma^*)}$$

where $\gamma^* = \alpha - \arcsin(D_d/D)$.

The lower boundary is expressed as follows:

(7) $$V_{1*} = V_2 \frac{\sin(K_2 - \gamma_*)}{\sin(K_1 - \gamma_*)}$$

where $\gamma_* = \alpha + \arcsin(D_d/D)$.

Obviously, with constant values of the courses K_1, K_2 and parameters γ^*, γ_* the boundaries of the dangerous area of speeds are straight lines. Figure 2 shows the area of unacceptable speeds for a pair of dangerously vessels' rapprochement, the courses of which are unchanged. In this example, the parameters of the rapprochement situation have the following meanings:

(8) $$\alpha_0 = 45^\circ, D_0 = 3 \text{ miles}, D_d = 1 \text{ mile}, K_1 = 90^\circ, K_2 = 180^\circ$$

At initial speeds $V_1 = 18$ knots and $V_2 = 21$ knots the closest approach distance is $D_{\min} = 0.23$ mile.
If the maneuver of the divergence of ships by a decrease in their speeds is characterized by short-term transient processes, then the determination of the speeds of the divergence V_{1y} and V_{2y} can be made using the considered area of dangerous speeds. In this case, the values of the indicated speeds are chosen from the boundary speeds. However, reducing the speed of vessels by braking, as a rule, requires considerable time. So, in this case, the inertial-braking characteristics of the vessels should be considered.

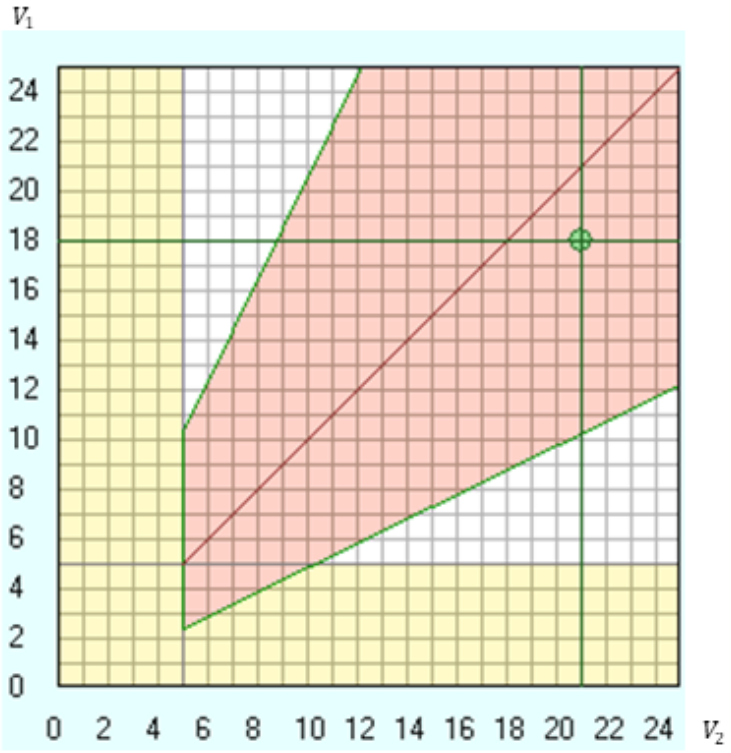

Figure 2. An area of dangerous ship speeds. *Source: Author's.*

The inertial-braking characteristics of ships are considered in the following way. Suppose the initial situation of a vessels' dangerous approach for the initial moment of time $t_0 = 0$ is characterized by a bearing α_0 and a distance D_0. The inertial-braking characteristics of vessels are considered in the following way. Since the bearing α_0 is set from the first vessel to the second, for the first vessel it is advisable to take the initial coordinates $X_{10} = 0$ and $Y_{10} = 0$. Obviously, the initial coordinates of the second vessel have values $X_{20} = D_0 \sin \alpha_0$ and $Y_{20} = D_0 \cos \alpha_0$.

Over time, the coordinates of the vessels X_{1t}, Y_{1t}, X_{2t} и Y_{2t}, as well as the current values of the distance D_t and bearing α_t change. Denote by c_{mx} a vessel, the transition period of change in speed of which is greater than or equal to the duration of the total transient process t_p. A vessel with a shorter transition period we denote as c_{mn}.

If the start time of the divergence maneuver t_n equal to the initial moment of time t_0, then vessels during the transition process t_p go the following distances:

(9)
$$L_{\text{mx}} = S_{\text{mx}},$$
$$L_{mn} = S_{mn} + V_{mny}(t_p - \tau_{mn})$$

where S_{mx} and S_{mn} – the distances that the ships c_{mx} and c_{mn} take to go respectively during the transient process of changing the speeds τ_{mx} and τ_{mn}.

By the time of the end of the general transient process t_p coordinates of vessels X_{mxp}, Y_{mxp}, X_{mnp} and Y_{mnp} are defined by the following expressions:

(10)
$$X_{mxp} = L_{mx} \sin K_{mx} = S_{mx} \sin K_{mx};$$
$$Y_{mxp} = L_{mx} \cos K_{mx} = S_{mx} \cos K_{mx};$$
$$X_{mnp} = L_{mn} \sin K_{mn} = [S_{mn} + V_{mny}(t_p - \tau_{mn})] \sin K_{mn};$$
$$Y_{mnp} = L_{mn} \cos K_{mn} = [S_{mn} + V_{mny}(t_p - \tau_{mn})] \cos K_{mn}.$$

Expressions of bearing α_p and distance D_p at the moment of time t_p:

(11)
$$D_p = \sqrt{(X_{mxp} - X_{mnp})^2 + (Y_{mxp} - Y_{mnp})^2}$$
$$\alpha_p = \arcsin\left(\frac{X_{mxp} - X_{mnp}}{D_p}\right)$$

At the time of the end of the transient process t_p the parameters of the movement of both vessels, as well as the relative course K_{otp}, become unchanged. Therefore, the distances value of the vessels' shortest rapprochement $D_{\min}$ can be calculated using the formula:

(12)
$$D_{\min} = \Delta_p D_p \, sin(K_{otp} - \alpha_p)$$

where $\Delta_p = \text{sign}[\sin(K_{otp} - \alpha_p)]$.

Setting the value of one of the speeds V_{1y}, find the value of the second speed V_{2y}, at which the obtained value of $D_{\min}$ is equal to D_d. If $D_{\min}(V_{1y},V_{2y}) < D_d$, then safe divergence with speed V_{1y} is impossible.

The values τ_{1y}, τ_{2y}, S_1 and S_2 the first and second vessels can be calculated using the formulas given in the work [34]. Using the obtained parameters and setting the speed V_{1y}, the values L_{mx} и L_{mn} are first calculated, and then the distance of the shortest vessels' rapprochement $D_{\min}$. In this case, you should start with the speed V_{2y}=V_2 and decrease it in each cycle by the selected value ΔV_{2y}.

Calculations continue until equality occurs $D_{\min}(V_{1y},V_{2y}) = D_d$, at which the sought value V_{2y} is determined. The values of speed V_{1y} are set from the range $V_{1y} \in [V_1, V_{1\min}]$, where $V_{1\min}$ – the minimum speed at which the vessel is steered. For each value V_{1y} from the specified range according to the described algorithm the speed V_{2y}, is calculated, satisfying the equality $D_{\min}(V_{1y},V_{2y}) = D_d$. As a result, the boundary of the area Ω_{Vj} of unacceptable vessels' speeds values will be obtained given the inertial-braking characteristics of their passive braking.

As an example, let us consider the situation of the vessels' dangerous rapprochement with the parameters: bearing α = 154°, distance $D = 4$ miles, vessel traffic parameters $K_1 = 237\,°$, $K_2 = 278\,°$, $V_1 = 15$ knots and $V_2 = 20$ knots, $D_d = 1$ mile.

In Figure 3 is shown the area Ω_{Vj} of unacceptable values of the vessels' speed, during the forming of which the inertial-braking characteristics of their passive braking had been considered. For divergence, points (V_{1y},V_{2y}) should be selected on the boundary Ω_{Vj}, for which equality $D_{\min}(V_{1y},V_{2y}) = D_d$ is true. So, Figure 3 shows the point on the boundary Ω_{Vj}, corresponding to the velocities $V_{1y} = 13.6$ knots and $V_{2y} = 13.2$ knots, for which $D_{\min} = 1.0$ mile is calculated by the software.

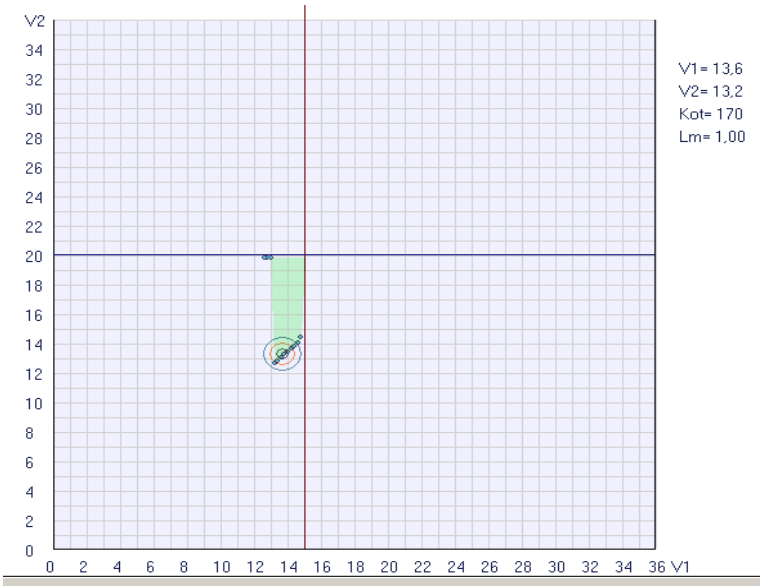

Figure 3. The area Ω_{Vj} of the unacceptable values of vessels' speeds. *Source: Author's.*

Thus, using the area Ω_{Vj}, it is possible to determine the values of the speeds obtained by passive braking, which ensure a safe divergence at a given distance.

If necessary, another type of divergence strategy can be used, in which one of the vessels changes its course, keeping its speed unchanged, and the second vessel on a constant course can reduce its speed. In this case, an area of inadmissible values of the course of one vessel and the speed of another vessel is formed, when the course of one vessel K_1 (K_2) and the speed of the second vessel V_2 (V_1) are selected as variable parameters. Then $P_x = V_2(V_1)$ and $P_y = K_1(K_2)$, but vessel traffic parameters K_2 (K_1) and V_1 (V_2) are unchanged.

Computer simulation modeling was used as an experiment to verify the validity of the proposed vessel collision avoidance methods. Let us present the results of checking the correctness of the method for determining the divergence maneuver by changing the courses of vessels. For this, a computer program was developed to simulate the divergence process.

As an example, the initial situation of a dangerous approach of vessels is shown in Figure 4. Figure 4 also shows the parameters of this situation.

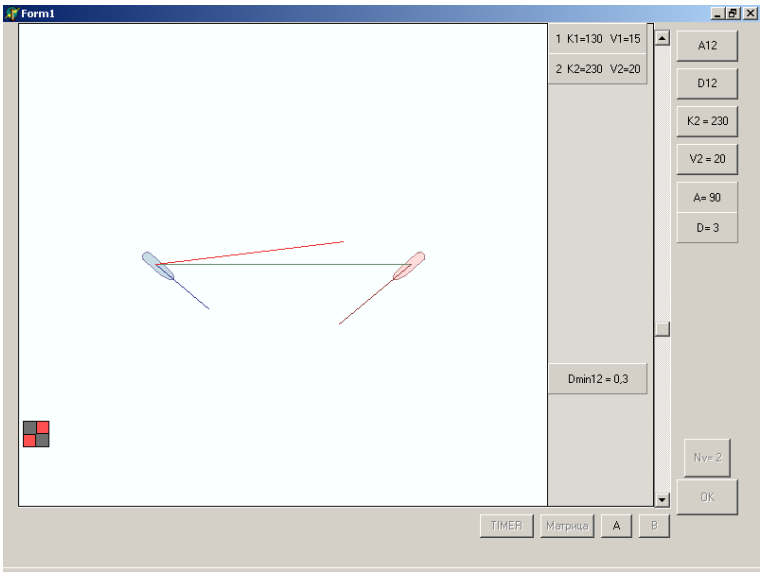

Figure 4. The initial situation of a dangerous approach of vessels. *Source: Author's.*

This situation is characterized by the closest approach distance of 0.3 miles. Therefore, it is necessary to select a diverging maneuver that increases the closest approach distance to 1 mile. For this purpose, an area of dangerous courses for this pair of vessels was formed, which is shown in Figure 5. To select a safe course of divergence of vessels, it is necessary to change the course of the first vessel by 19˚, and of the second – by 11˚, i.e., up to 111˚ and 219˚ respectively. In this case, the point of intersection of the current courses is on the border of the area of dangerous courses, and the closest approach distance of 1.07 miles is approximately equal to the maximum allowable distance, the given value of which is assumed to be 1 mile, as shown in Figure 5.

To check the correctness of the chosen courses of vessels' divergence, the maneuver of diverging ships was played using the third module of the simulation program.

At the same time, an animation of the current position of vessels with the selected evasion courses is displayed on the monitor screen, and the current value of the distance between vessels is shown in the upper left corner of the screen.

Figure 6 shows the situation of vessels' divergence at the time of 5 s.

Figure 7 shows the situation of the closest approach of vessels now of time equal to 351 s, at which the distance of the closest approach is equal to 1.06 miles, i.e., practically the maximum allowable distance.

Figure 8 shows the situation when the maneuver is completed.

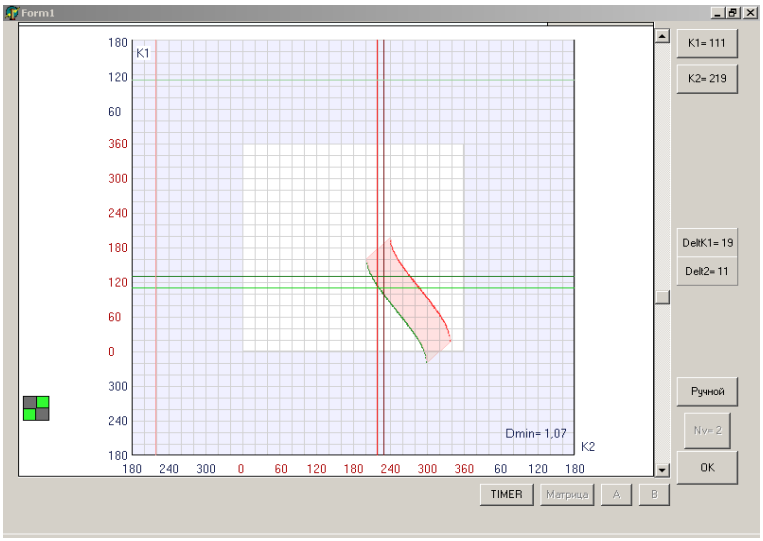

Figure 5. The selection of a safe course of divergence of vessels. *Source: Author's.*

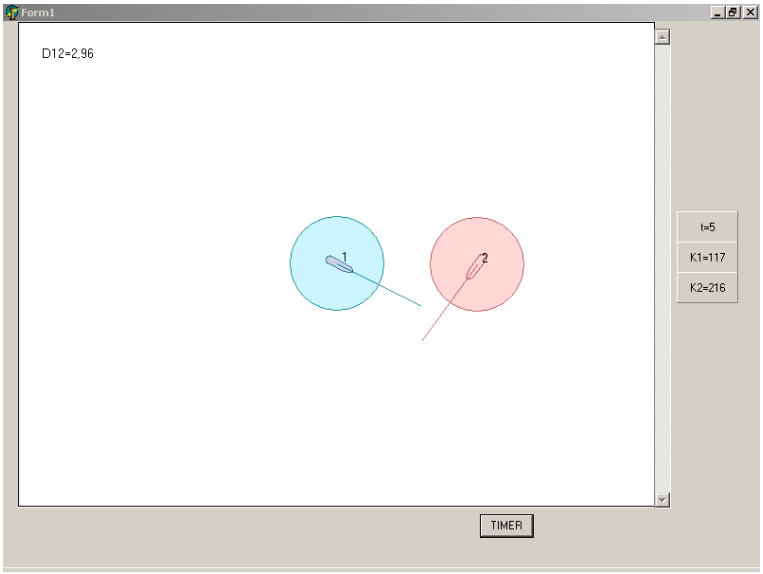

Figure 6. The initial situation when playing the maneuver. *Source: Author's.*

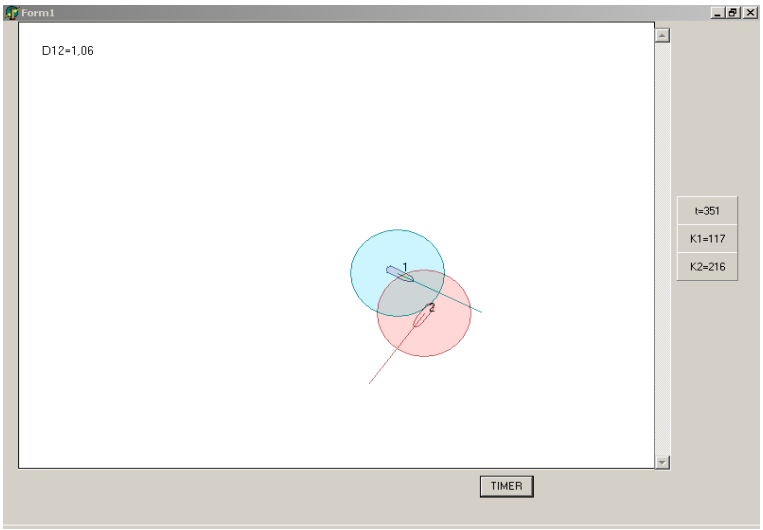

Figure 7. The situation of the closest approach of vessels. *Source: Author's.*

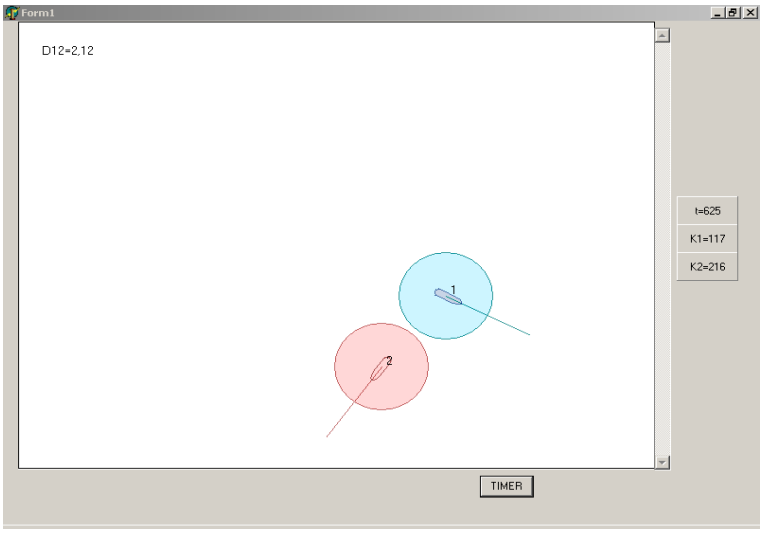

Figure 8. The completion of the process of playing the maneuver. *Source: Author's.*

Simulation modeling has shown the correctness of the proposed method of vessel divergence by changing their courses when using a dangerous course area.

In the event of a situation of dangerous approach, in the presence of sufficient water space, the method of vessel divergence by changing courses should be applied. If there are navigational restrictions, then it is advisable to use a divergence maneuver by changing the course of one vessel and the speed of another vessel. If it is impossible to perform such a maneuver, it is necessary to use the method of divergence by changing the speeds of both vessels at constant courses.

Impact

The developed method for the formation of areas of parameters' unacceptable values of the vessels' movement during their remote control offers navigators a behavior strategy for each of the ships, depending on the situation of approaching. The agreed method is applicable for the safe divergence of two or more vessels in narrow waters.

The perspectives for the inland waterway transport development are very great virtually in all countries. The EC White Paper on Transport notes that goods by inland waterways (IWW) are significantly inferior in volume to other modes of inland transport, in particular rail and road. Thus, freight traffic in terms of IWW in Poland is 6 times less than in France and almost 60 times less than in Germany. Moreover, they do not exceed 1% of freight traffic by road [35]. In Ukraine, the situation is similar. At the same time, in the United States, the share of freight traffic in IWW averages approximately 11% of all intercity freight traffic.

The inland navigation reduction in comparison to road transport can be explained by the determining influence of the geographic factor. The Danube countries are in the best conditions, characterized by a higher degree of IWW utilization along the Rhine and Danube rivers. Italy, Poland, Ukraine and other countries have a large list of important bottlenecks with low capacity. In addition, E waterway networks have a significant number of missing links, listed in the UNECE Blue Book [36]. The Polish government considers it necessary to upgrade class I, II or III to class Vb on the "major bottlenecks" of routes E 30, E 40 and E 70. However, today nothing is known about such projects, which would be included in the agenda of the Polish government. At the same time, in the indicated water area the majority of a waterway has a width below 8.5 times of the vessels' beam, which counts them as IWW with complicated navigation, that is, to "narrow water". In Ukraine, the IWW infrastructure is also expanding with the inclusion of missing links in the E-category IWW network [26]. However, such areas are characterized as narrow water with insufficient maximum draught (1.20 m) [36].

In addition, the number of voyages during the navigation period is increasing every year. That is, an increase in the intensity of navigation along the IWW complicates the already rather dangerous process of divergence of a vessels' group of two or more vessels in waterways.

Under such conditions, the introduction of the developed method using remote control will expand the possibilities of vessel divergence in narrow waters for safe navigation based on joint divergence maneuvers. In the absence of the possibility of changing the vessel course in case of a dangerous rapprochement in narrow waters, the situation of preventing a dangerous vessels' rapprochement by changing the speed of one or each of the vessels is considered. Thanks to the research carried out, the areas of the vessel movement parameters are considered, in which the vessels' collision can be prevented only by changing the speed.

One of the projects, the main theme of which is the implementation of a new concept of communication between interacting vessels based on the VHF data exchange system (VDES) of the next generation of AIS communication, is the LAESSI project (Dresden, Germany) [37]. One of the advantages of this project is the transmission of all necessary phase and code corrections within a limited amount of data.

It should be considered that the global system for mobile devices (GSM) does not currently meet the requirements for the availability and stability of communications on inland waterways. Therefore, the possibility of using the Automatic Identification System (AIS) to transmit data between evading vessels in real-time in complex scenarios is being studied.

The implementation of VTS and VTMS into the management of the divergence process eliminates the need for mutual coordination of vessels' maneuvers by the interaction mechanism, i.e., the principle of remote control of the divergence process is applied.

It is expected that the implementation of the proposed scientific and technical solution will have a social and ecological effect, bring economic benefits to society, and prevent environmental damage. This is attributed to the fact that it will be possible not to expand IWW to the detriment of social projects, but to optimize the parameters of vessel safe domains during divergence.

The use of areas' unacceptable values of the vessels' movement parameters during their remote control, obtained by the developed method, will generally form the competitiveness of freight transport on IWW and a positive effect on the environment due to emission reduction at road freight due to decreasing in the amount of freight traffic. Thus, a method of vessels' divergence maneuver has developed. It has applied innovative aspects for forming areas of unacceptable values of vessel movement parameters. The developed method is based on a larger number of vessel variable parameters compared to the existing technologies. This method improves the efficiency of navigation in narrow waters while reducing material and energy costs.

It should also be noted that the use in the developed method of remote control of the process of diverging vessels provides for the availability of qualified personnel of both VTS and VTMS. This will contribute to the creation of new jobs, the number of which will continue to increase as grown the implementation scale of the proposed development.

Conclusions

A general method for the formation of an area of unacceptable values of the parameters of the vehicles' movement has been proposed. The combination of the developed method and algorithm for the formation of an area of unacceptable values of vehicles' traffic parameters with the categories of COLREGs rules makes it possible to increase the efficiency of collision avoidance following the requirements of the specified protocol.

The obtained analytical dependencies for calculating the boundaries of the area of unacceptable values of the vessels' course and the area of unacceptable values of their speeds make it possible to carry out the so- called "road tests" for autonomous marine vehicles before their operation, considering the parameters of the test environment. Situations of avoidance of dangerous approach of vessels not only by changing their courses, but also by changing the speed of one or each of the vessels is considered. This is important since, in narrow waters, vessels cannot change course in case of a dangerous rapprochement, therefore, situations have been considered when a collision of vessels can only be prevented by changing the speed.

The presented graphical display of the area of unacceptable values of vessel movement parameters facilitates the visual perception of given situations of dangerous approach and, thereby, accelerates the decision-making on the safe navigation parameters of a vessels' group.

In addition, the proposed method can be generalized to other (besides maritime, both surface and underwater) environments of navigation, such as aircraft flight rules, movement of ground-based autonomous unmanned/ uncrewed vehicles with remote control, etc.

Conflict of interest

There are no conflicts to declare.

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ECONOMIC ANALYSIS OF ARTIFICIALLY ROUGHENED SOLAR AIR HEATER WITH V-SHAPED RIBS

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Highlight

Life cycle savings as performance evaluation criterion is used to evaluate the economic performance of solar air heater.

Abstract

Due to the minimal transfer of heat from absorber plate to moving air in the duct, solar air heaters have low performance. One of the procedures to augment the heat transfer by substantial amount is by utilizing artificial roughness, by which the performance can be improved considerably. In this study, an economic investigation of solar air heater embedded with artificial roughness is accomplished numerically employing v-shaped roughness, with the objective of optimising life cycle solar savings. The non-dimensional parameters of roughness, namely, angle of attack (α), roughness pitch (p/e) and roughness height (e/D_h) are examined

by varying temperature rise over the solar air heater (*ΔT*) and solar radiations (*I*) for different economic parameters values i.e., cost of collector, cost of roughness elements, and cost of conventional fuel.

Keywords
solar air heater; heat transfer; artificial roughness; economic analysis; life cycle savings.

Introduction

Solar air heater (SAH) is the most used heat exchanger which is used to convert the solar radiations coming onto the earth's surface into heat. This heat is then transferred to the flowing air below the absorber plate of SAH. As the thermal conductivity value of air is less, the transfer of heat among the air and the absorber plate is ineffective. Owing to this, numerous alterations to the SAH are considered by various researchers to elevate the transfer of heat between the air and absorber plate. One among the most successful approach to augment the transfer of heat in SAHs is by using artificial roughness in the form of ribs below the absorber plate. The artificial rib roughness introduces the disturbance in the flow by mixing and promoting turbulence in fluid flow, thereby breaking the viscous sublayer at absorber plate's surface, and induces secondary flows, which augments the transfer of heat and accumulate less rise in pumping power.

Prasad and Mullick [1] incorporated artificial roughness in SAH to elevate the transfer of heat initially. They used protruding wires for improving the plate efficiency factor of SAHs from 0.63 to 0.72, corresponding to an enhancement in the performance of 14%. Momin et al. [2] examined the impact of v-shaped roughness in a duct of the SAH, and recorded that for v rib, the utmost elevation in Nusselt number (*Nu*) and friction factor (*f*) was 2.30 and 2.83 times concerning smooth duct, respectively. Hans et al. [3] used multiple v-rib as roughness in SAH duct and reported a maximum enhancement in *Nu* and *f* of 6 and 5 times concerning smooth duct. Chamoli and Thakur [4] used v-shaped baffles with perforation and reported enhancement in *Nu* and *f* of 2.2 and 5.5 times concerning smooth duct. Gawande et al. [5] incorporated chamfered square ribs and reported a maximum thermal-hydraulic performance of 2.047. Maithani and Saini [6] applied v ribs with gaps at symmetry and recorded an utmost elevation in *Nu* and *f* of 3.6 and 3.67 times concerning smooth tube. Nadda et al. [7] employed multiple arc protrusions obstacles in a jet impingement SAH and reported that the optimal improvement is achieved at a width ratio of five, angle of attack of 55°. Bisht et al. [8] compared different roughness geometries based on their thermal and exergetic performance and gave a comprehensive review of the roughness geometries. Singh and Singh [9] incorporated square cross sectioned transverse ribs as roughness and reported the highest thermo-hydraulic performance factor of 1.43 at a pitch ratio value of 10. Chamoli et al. [10] used winglet vortex generators as roughness and reported thermal enhancement factor ranging from 1.72 to 2.20. Maithani et al. [11] incorporated spherical shaped turbulence promoters and reported a maximum value of enhancement factor of 2.98. Similar strategies to raise the heat transfer using different novel inserts to augment thermal performance of heat exchangers was reported by various researchers like Bahuguna et al. [12], Paneliya et al. [13], Bahuguna et al. [14], Kumar and Chandra. [15]. Bisht et al. [16] employed v ribs in conjunction with perforated baffles of the shape of v and recorded that utmost *Nu* and thermal efficiency comes at an open area ratio of 12%. Choi and Choi [17] employed transverse triangular block type ribs in SAH and reported an utmost augmentation in *Nu* of 3.37 over smooth duct. Ghritlahre et al. [18] studied the works related to energy and exergy analysis of distinct types of solar air heaters and reported that the energetic and exergetic efficiencies of distinct types of SAHs varied from 2.05% to 82% and 0.01% to 60.97%, respectively. Singh et al. [19] used kite-shaped ribs in SAH and reported an utmost augmentation in *Nu* of 4.8 times than that of a smooth tube, and highest thermohydraulic performance of 2.9. Azadani and Gharouni [20] employed cylindrical shape roughness and reported a thermohydraulic performance of 1.20 for best parameters of roughness. Haldar et al. [21] numerically investigated artificial wavy ribs in SAH and reported the optimum thermohydraulic performance parameter of 1.96. Likewise, a number of investigators used different orientations of ribs to enhance *Nu* with a minimal increase in *f*.

According to the author's information, the thermal performance of SAH along with its economic analysis have never been reported together, therefore there is a need to assess the value of solar thermal systems by considering the economic aspects to check their feasibility. Once the thermal performance of SAH is evaluated, the methods for making economic evaluations are required. Based on life cycle solar savings, an economic analysis of an artificially roughened SAH utilising v-shaped ribs as roughness was conducted in this study. The impact of roughness parameters, namely, e/D_h, p/e, and α, on life cycle savings (*LCS*) of SAH for various values of collector cost factors, with respect to design parameter i.e., insolation (*I*) and temperature rise parameter ($\Delta T/I$) have been studied. This research is conducted in Dehradun, which is the capital of Indian State Uttarakhand where temperature varies from around 10°C to 40°C in a year, with mostly sunny all around the year making it appropriate to use solar energy utilization system. Also, as this research work is based on financial

aspect of solar air heater, hence it is imperative to know the conventional solar air heater cost which is around $1/Watt, and if artificial roughness is applied to it than the cost may increase by around 25%.

System Model

For this investigation, below the SAH's absorber plate a continuous v-down ribs are applied using a wire as roughness elements. The parameters of roughness i.e., e/D_h, p/e, and α have been varied. The useful heat gain (Q_u), is determined from the following relationship for SAH:

(1) $$Q_u = F_R A_p\{I(\tau\alpha) - U_l(T_o - T_i)\}$$

where, A_p is surface area of absorber plate, ($\tau\alpha$) is transmittance-absorptance product U_l is Overall heat loss coefficient, T_o and T_i is outlet and inlet temperature of air, F_R is heat removal factor given by,

(2) $$F_R = \frac{GC_p}{U_l}\left\{exp\left(\frac{F'U_l}{GC_p}\right) - 1\right\}$$

where, G is mass velocity of air, C_p is specific heat of air, F' is collector efficiency factor.
The roughness geometry of repeated continuous v-down ribs analysed in this work is shown in Figure 1.

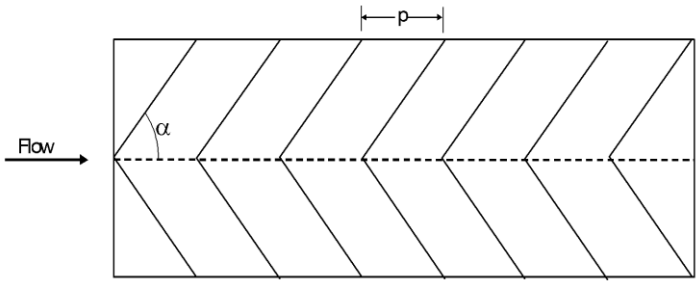

Figure 1. Continuous v-down rib geometry analysed in present work.

It is seen from the geometry of multiple v-shape rib roughness investigated by Hans et al. [3], that if the width of single v-rib (w) is same as width of plate i.e. (W/w) = 1, the roughness geometry so obtained will be identical with the one, which is been considered in the present study (Figure 1). So, by using the value of W/w as 1 in the correlations of Nu and f given by Hans et al. [3], the modified correlations of Nu and f are presented in Eqs. 3 and 4, respectively, and are used in the present study:

(3) $$Nu = 0.0000335(Re)^{0.92}\left(\frac{e}{D_h}\right)^{0.77}\left(\frac{p}{e}\right)^{8.54}\left(\frac{\propto}{90}\right)^{-0.49} exp\left\{-0.61\left(ln\frac{\propto}{90}\right)^2\right\} exp\left\{-2.0407\left(ln\frac{p}{e}\right)^2\right\}$$

(4) $$f = 0.000447(Re)^{-0.3188}\left(\frac{e}{D_h}\right)^{0.73}\left(\frac{p}{e}\right)^{8.9}\left(\frac{\propto}{90}\right)^{-0.39} exp\left\{-0.52\left(ln\frac{\propto}{90}\right)^2\right\} exp\left\{-2.133\left(ln\frac{p}{e}\right)^2\right\}$$

The top loss coefficient (U_t) in the present study is found by using the correlation reported by Malhotra et al.[22] as:

(5) $$U_t = \left[\frac{N}{\left(\frac{C}{T_m}\right)\left(\frac{T_m - T_a}{N + f_e}\right)^{0.252}} + \frac{1}{h_w}\right]^{-1} + \left[\frac{\sigma(T_m^2 + T_a^2)(T_m + T_a)}{\frac{1}{\varepsilon_p + 0.0425N(1 - \varepsilon_p)} + \frac{2N + f_e - 1}{\varepsilon_g} - N}\right]$$

where, N is number of glass covers in SAH, C is an empirical factor (= $620(1-0.000051\beta^2)$ for $0°<\beta<70°$ and for $70°<\beta<90°$ use $\beta = 70°$, β is tilt angle of SAH), T_m is mean plate temperature, T_a is ambient temperature, f_e is an empirical factor (= $(1+0.089h_w - 0.1166h_w\epsilon_p)(1+0.07866N)$), h_w is wind heat transfer coefficient (=$5.7+3.8V_w$, V_w is wind speed), σ is the Stefan Boltzmann constant, ϵ_p is emissivity of absorber plate, ϵ_g is emissivity of glass cover. The operating and system parameters employed for the present investigation are presented in Table 1.

Table 1. Specification and range of parameters of the investigation.

Fixed Parameters	**Values**	**Variable Parameters**	**Range of parameters**
L	2	e/D_h	0.020-0.044
W	1	p/e	6-12
H	0.025	α	30-75
N	1	$\Delta T/I$	0.002-0.025
$(\tau\alpha)$	0.80	I	1000
T_a	300	C_C	1000-20000
f_l	0.8	C_R	2-20
d_l	15	C_F	300-2000
i_f	4		
C_E	5		
$i_{.e.,}$	4		
d	10		
i_m	5		
n_l	5		
n	10		

Procedure for Prediction of Economic Performance

The procedure for calculating the absorbed irradiation and the heat losses for conventional flat plate SAH is used. Further, by knowing the thermal performance, economic evaluation is being done, i.e., life cycle savings are calculated.

If the system requires a total investment 'C' of which a fraction f_l is taken as a loan amount, then loan taken, and down payment are given as:

$$Loan\ taken = f_l C$$

$$Down\ payment = (1 - f_l)C$$

Assuming the interest rate on loan to be d_l and that it is to be paid back in equal annual instalments over a period of n_l years. For any year j, the annual repayment on loan is given as:

(6) $$Annual\ repayment\ on\ loan = \frac{d_l(f_l C)}{\left[1 - \left\{\frac{1}{(1+d_l)^{n_l}}\right\}\right]}$$

The collector cost is determined from the conventional collector cost factor C_C, which is the unit area cost of smooth surface. In this, the cost of roughness configurations fixed to the absorber plate is also added. If C_R is the roughness cost factor that represents material cost and the fabrication cost per unit cubic meters of roughness material per unit area of the collector plate.

Then,

(7) $$C = A_P(C_C + C_R V_R)$$

where, $A_P = W \times L$

where w and L are width and length of the absorber plate.

(8) $$V_R = \frac{\pi D_h \left(\frac{e}{D_h}\right)}{4\left(\frac{p}{e}\right) Sin\left(\frac{\alpha}{2}\right)}$$

(9) $$D_h = \frac{2 \times W \times H}{(W + H)}$$

V_R is the volume of the material attached as roughness to absorber plate in cubic metres per meter square of collector plate area, D_h is hydraulic diameter of the solar air heater duct.
The annual savings of conventional fuel is converted into money by multiplying it with the cost factor of conventional fuel (C_F), which is the unit cost of conventional fuel, which increases at the rate of i_f per year and is then calculated for j^{th} year as:

(10) $$Fuel\ Savings = C_F E\left(1 + i_f\right)^{(j-1)}$$

where E is the annual solar energy collected.
The cost of maintenance is taken as M in the first year of operation, and that it increases at the rate of i_m every year, the maintenance cost for the j^{th} year is given as:

(11) $$Maintenance\ cost = M(1 + i_m)^{(j-1)}$$

This pumping energy (E_P) for the running of a pump to continuously flow air in solar collector comes from the electricity. So, the electricity bill over a year of this pumping energy is calculated by multiplying the cost factor of electricity (C_E) by the pumping energy. Let this cost of electricity increases at the rate of i_e per year. So, the electricity bill for running the pump in j^{th} year is given as:

(12) $$Electricity\ Bill = C_E E_P (1 + i_e)^{(j-1)}$$

Neglecting the tax deduction on the interest component of loan repayment and tax deduction on depreciation, the annual solar savings (*ASS*) in the j^{th} year is given as:

(13) $$ASS = C_F E\left(1 + i_f\right)^{(j-1)} - \frac{d_l(f_l C)}{\left[1 - \left\{\frac{1}{(1 + d_l)^{n_l}}\right\}\right]} - M(1 + i_m)^{(j-1)} - C_E E_P (1 + i_e)^{(j-1)}$$

This equation is valid for $j \leq n_l$.

The *LCS* over a period of *n* years for the system is obtained by summing up the present worth of the annual solar savings and considering initial down payment. Thus, *LCS* is given by:

(14) $$LCS = \sum_{j=1}^{n} (ASS)_j - (Initial\ down\ payment)$$

Taking market discount rate as '*d*', and *ASS* from Eq. 13, we obtain *LCS* as given in Eq. 15.

The Eq. (15) is valid for $n \geq n_l$, $d \neq i_f$, $d \neq i_m$, and $d \neq i_f$.

$$LCS = -(1-f_l)C + \frac{C_F E}{(d-i_f)}\left\{1-\left(\frac{1+i_f}{1+d}\right)^n\right\} - \frac{d_l(f_l C)}{\left[1-\left\{\frac{1}{(1+d_l)^{n_l}}\right\}\right]}\frac{1}{d}\left\{1-\frac{1}{(1+d)^{n_l}}\right\} - \frac{M}{(d-i_m)}\left\{1-\left(\frac{1+i_m}{1+d}\right)^n\right\} - \frac{C_E E_P}{(d-i_e)}\left\{1-\left(\frac{1+i_e}{1+d}\right)^n\right\} \quad (15)$$

Results and Discussions

The results obtained from the mathematical simulation to evaluate the economic performance viz. *LCS* of a solar thermal collector have been reported and discussed in this section.

Life Cycle Savings

Figure 2 reveals that the values of *LCS* are negative for some years in each case, although this number depends on the values of the *ΔT/I*, a lower value of this parameter requires a longer period for the *LCS* to become positive because of higher electricity bill due to high mass flow rate. Thus, larger pumping power is required even if it possess a relatively higher thermal efficiency. The maximum *LCS* are seen in this plot for the *ΔT/I* of 0.010 and then with an increase in *ΔT/I*, LCS decreases. This is due to low Q_u for the higher values of *ΔT/I* which in turn reduces fuel savings and yields lower values of *LCS*.

From Figures 3 and 4 it is seen that the cost factor of collector has a significant impact on *LCS*, a lower value of collector cost of Rs. 1000/m^2 results in a breakeven (*LCS* equal to zero) in less than 3 years, whereas if the cost of collector is 20 times (Figure 4), the breakeven is reached much later (in almost 9 years).

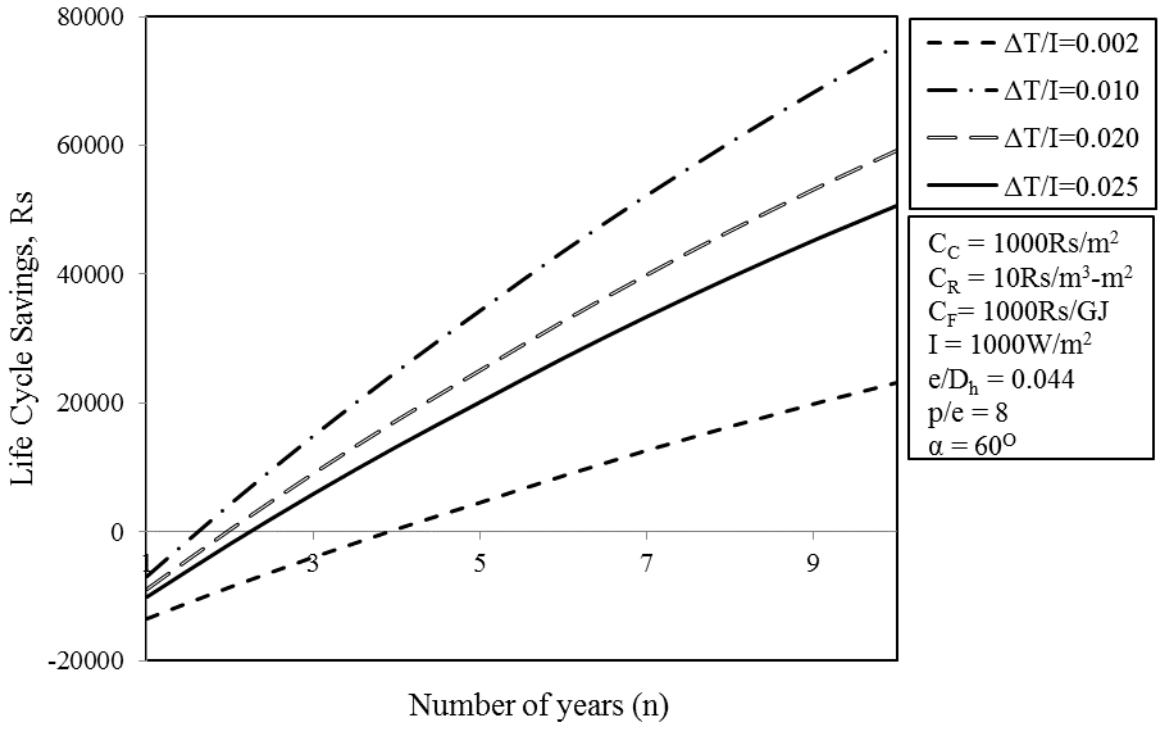

Figure 2. Variation of LCS with number of years for different ΔT/I.

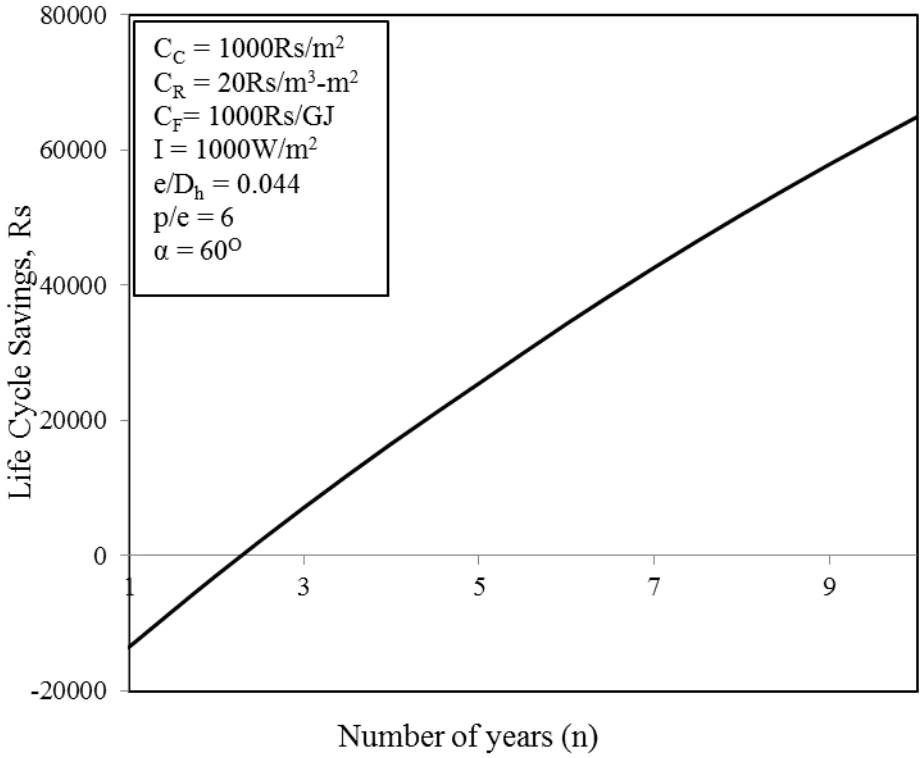

Figure 3. Variation of *LCS* with number of years with C_C as 1000Rs/m^2.

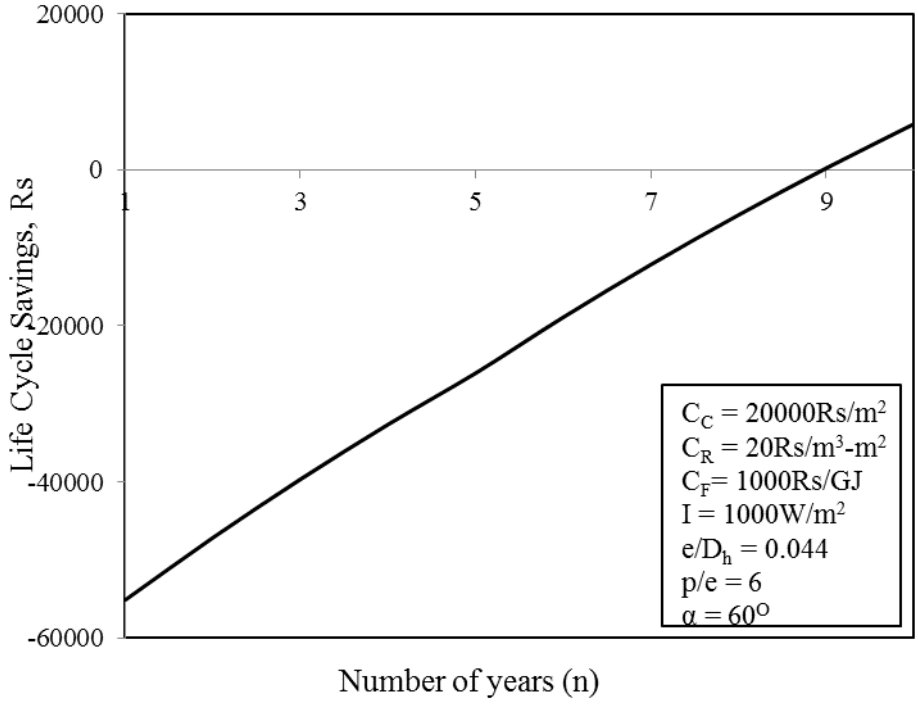

Figure 4. Variation of *LCS* with number of years with C_C as 20000Rs/m^2.

Effect of Cost Factor of Collector on LCS

It can be seen clearly from the Figures 5 and 6 that *LCS* value decreases sharply with the increase in C_C. Further, a very large value may even result in a negative value. It can also be seen that *LCS* increase as the values of $\Delta T/I$ raises, and after attaining maximum value, *LCS* declines with further increase of $\Delta T/I$. Very low values of $\Delta T/I$ are accompanied with significantly large values of pumping power. Furthermore, high thermal efficiencies accumulated cannot compensate the high electricity bill of pumping power. While higher values of $\Delta T/I$ results

in lower thermal efficiency and hence lower fuel savings leading to lower values of *LCS* as can be seen from Figure 5. Figure 6 has been plotted to reveal the above-mentioned results more clearly where an increase in C_C values always results in lower values of *LCS*, a linear variation for any fixed value of $\Delta T/I$ is seen.

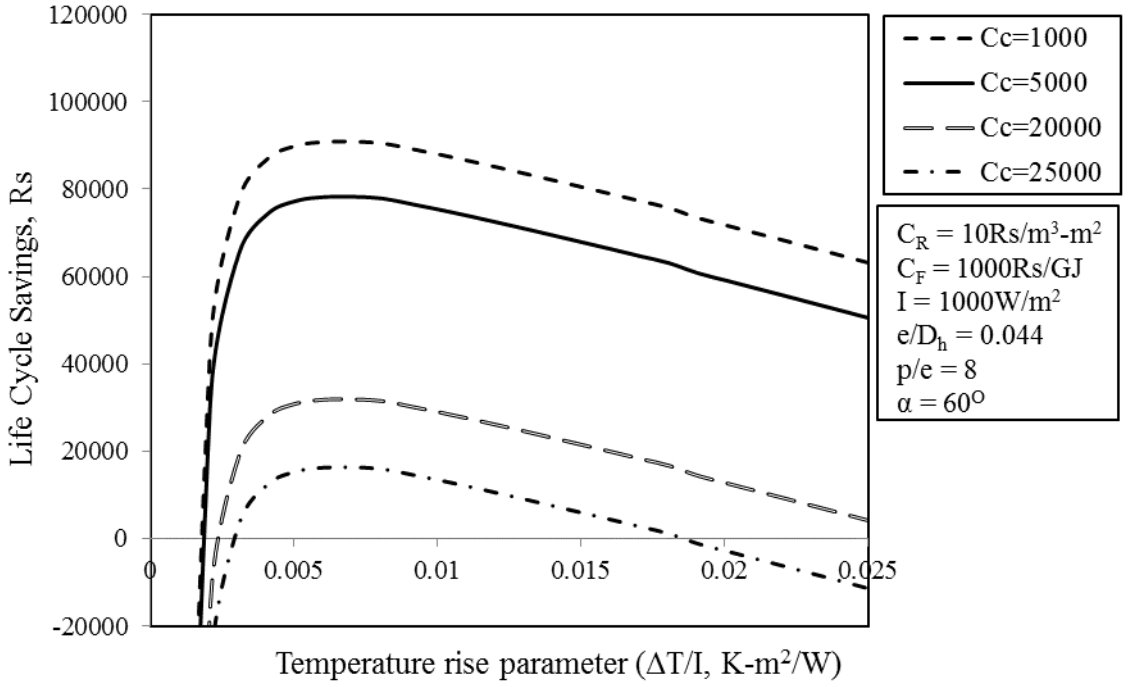

Figure 5. Variation of *LCS* with $\Delta T/I$ with different C_C.

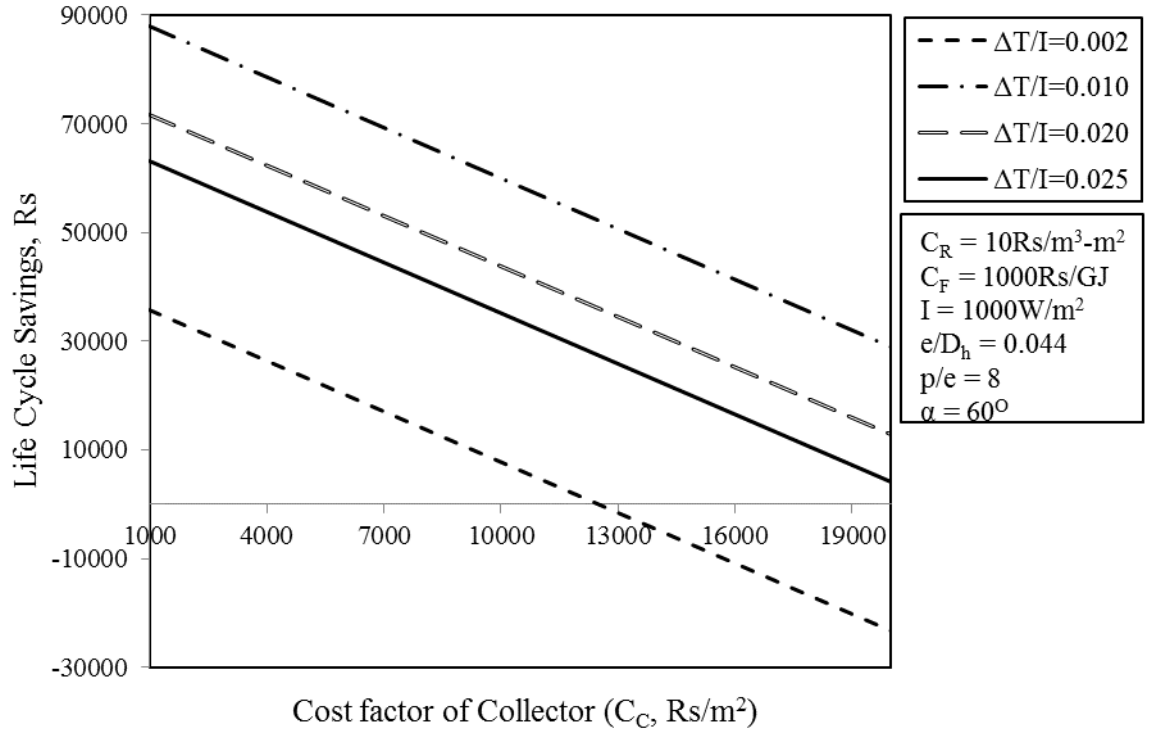

Figure 6. Variation of *LCS* with C_C with different $\Delta T/I$.

Effect of Artificial Roughness Parameters on LCS

From Figure 7, it is to be noted that as the e/D_h of the roughness elements increases, *LCS* decreases in the case of lower values of $\Delta T/I$, whereas for the higher values of $\Delta T/I$, the *LCS* increases. It is also seen that there is no single optimum value of roughness height for the entire range of temperature rise parameter that would give the maximum value of *LCS*. In Fig. 8 the values of *LCS* are presented for various e/D_h values, where it is revealed

that functional changes depend on *ΔT/I*; a lower value of *ΔT/I* show a decrease in the value of *LCS* as roughness height is increased from a value of 0.020 to 0.044 indicating best value of 0.020, whereas corresponding to higher *ΔT/I* value of 0.025, the best value is 0.044 (that corresponds to maxima in *LCS*). The fact that lower *ΔT/I* correspond to higher electric power expenses involved with pumping power as well as the cost of roughness components explains the difference in the optimal values. Whereas, corresponding to higher *ΔT/I*, the Q_u and the resultant conventional fuel cost savings are likely to predominate.

Plots showing the effects of *p/e* of roughness elements on *LCS* are presented in Figures 9 and 10. Where for lower values of *ΔT/I*, *LCS* obtains maximum value corresponding to *p/e* of 12. Further, for *ΔT/I* > 0.008 the utmost value of *LCS* is found for *p/e* value of 10. These results have been replotted in Figure 10 where variation of *LCS* with *p/e* is shown for different values of *ΔT/I* and it is revealed that the values of LCS increases first with increase in *ΔT/I* and after obtaining maxima at *ΔT/I* value of 0.010 it starts declining; for *ΔT/I* value of 0.010, highest *LCS* is obtained for *p/e* value of 12.

The effect of *α* on *LCS* are presented in Figures 11 and 12. Where Figure 11 shows that the maximum values of *LCS* correspond to lowest value of *α* of 30° for lower *ΔT/I* whereas the highest value of *α* of 75° correspond to maxima in *LCS* when *ΔT/I* values are high. These results are again shown in different manner where variation of *LCS* with *α* are shown for different values of *ΔT/I* and it is revealed that maximum LCS is obtained for *ΔT/I* value of 0.010. Also, the values of LCS first increases with *ΔT/I* and after attaining maxima, it starts decreases. For the maximum value of LCS obtained for *ΔT/I*=0.010*, the α* value is 75°.

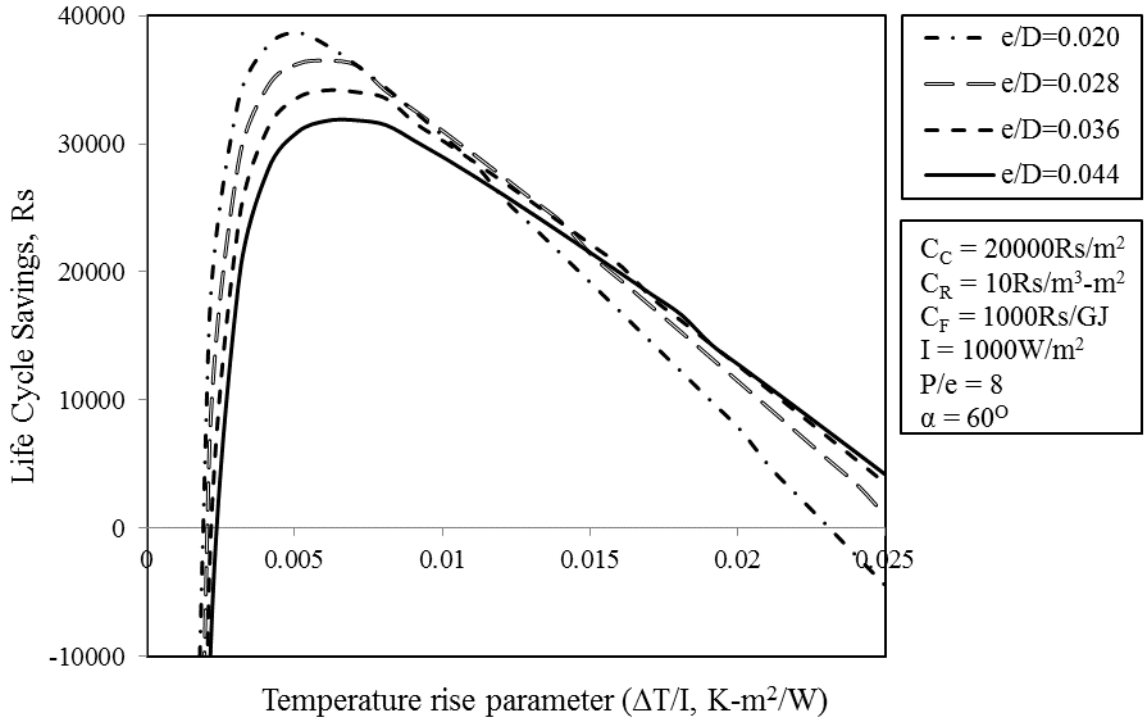

Figure 7. Variation of *LCS* with *ΔT/I* for different e/D_h.

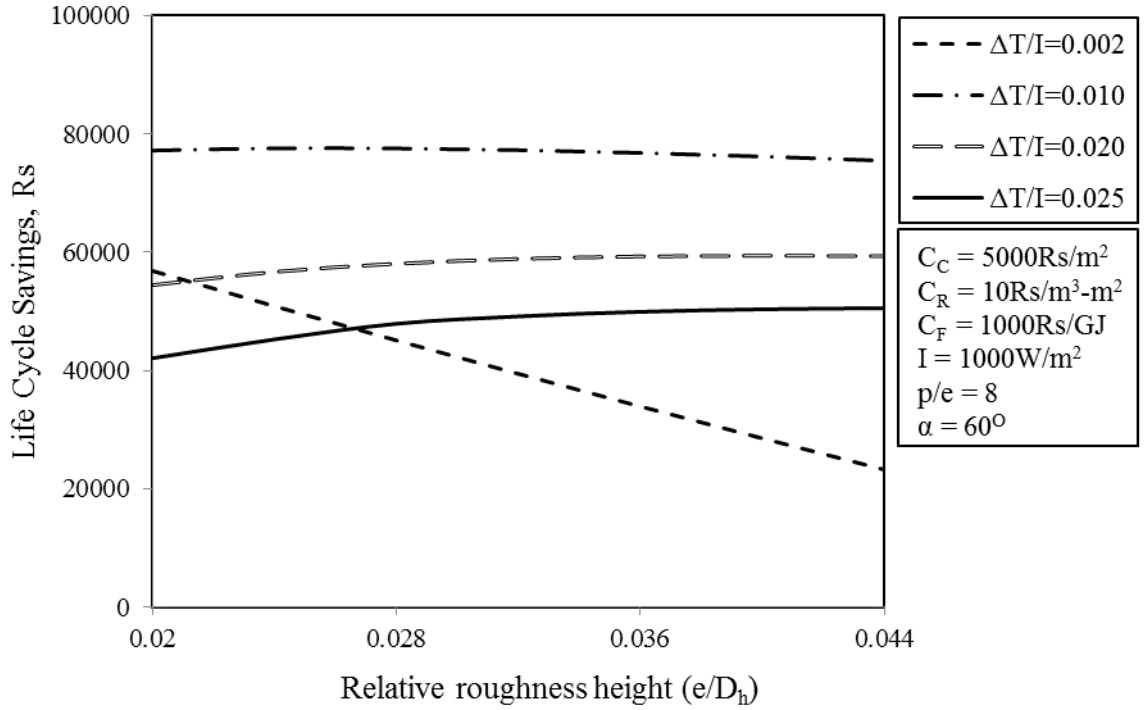

Figure 8. Variation of *LCS* with e/D_h for different $\Delta T/I$.

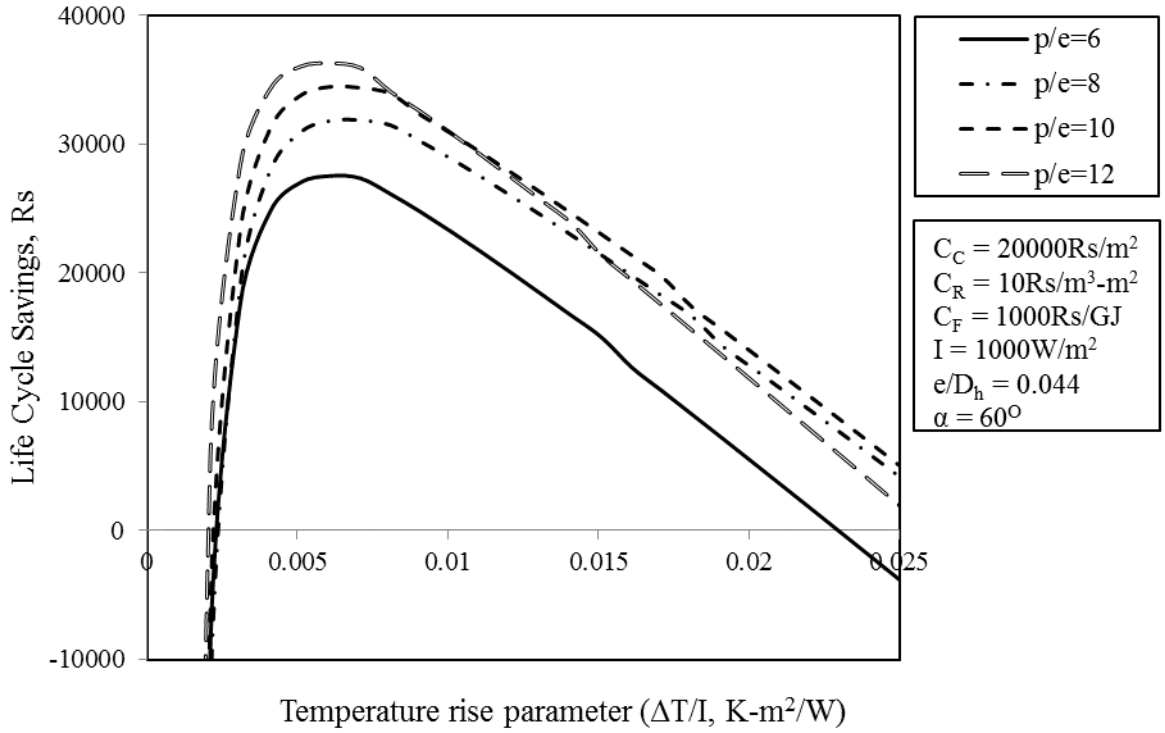

Figure 9. Variation of *LCS* with $\Delta T/I$ for different *p/e*.

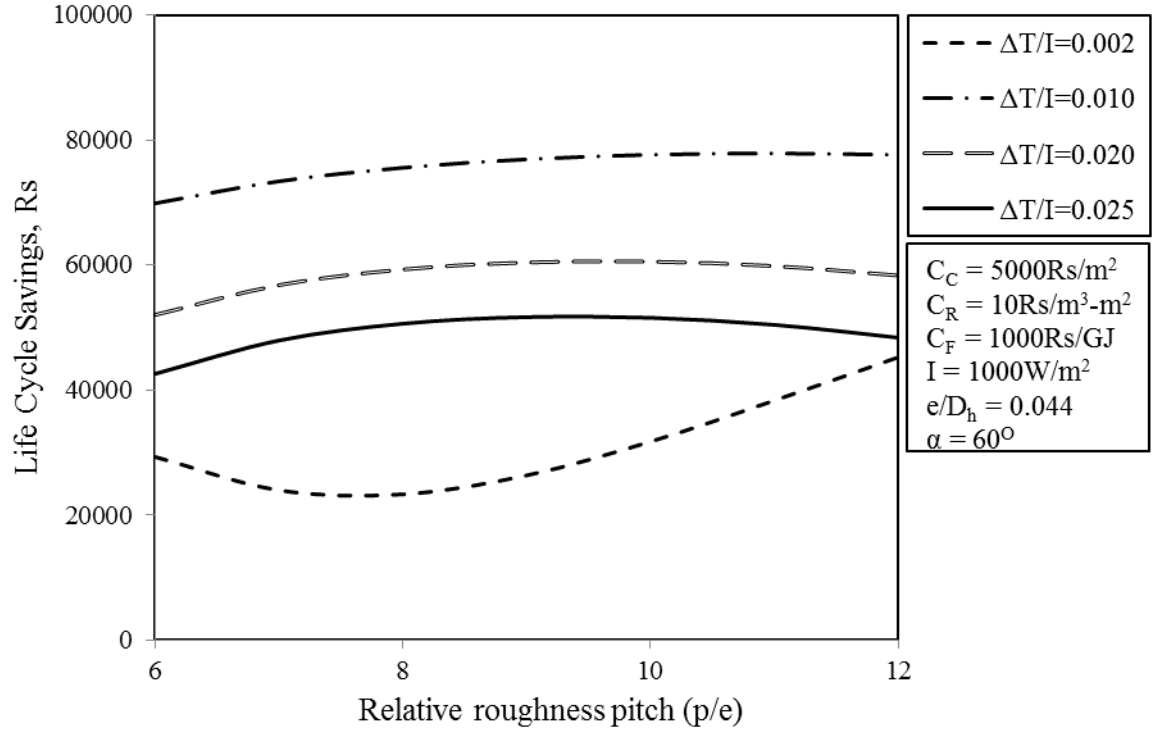

Figure 10. Variation of *LCS* with *p/e* for different *ΔT/I.*

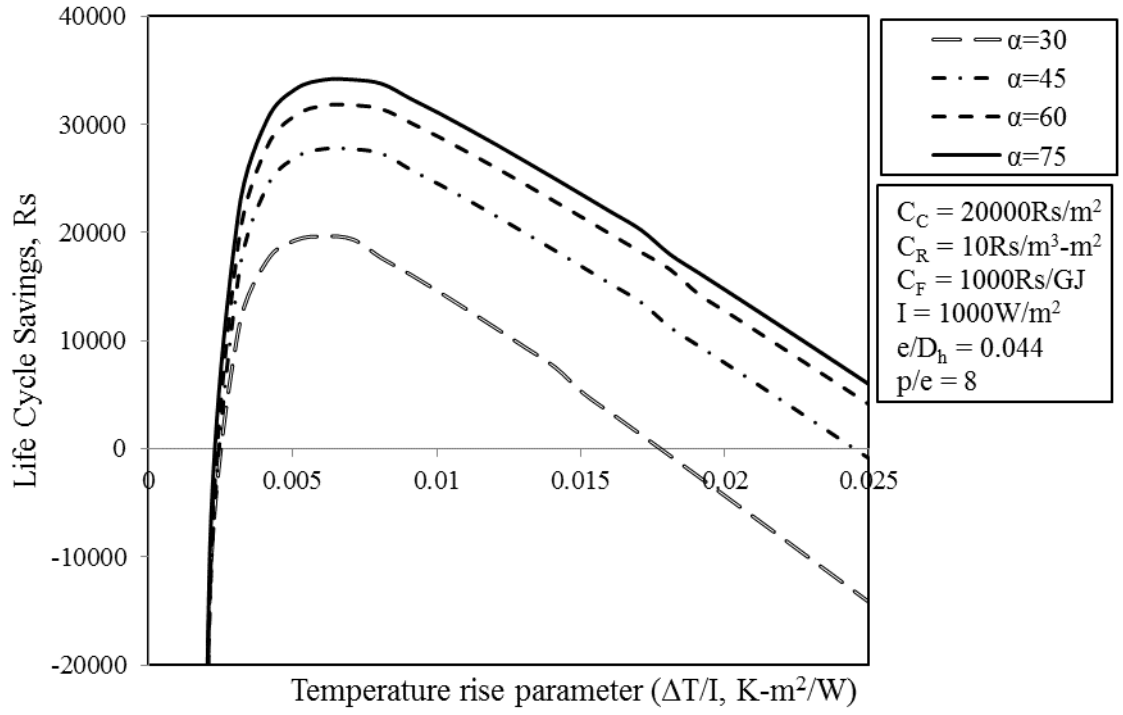

Figure 11. Variation of *LCS* with *ΔT/I* for different *α.*

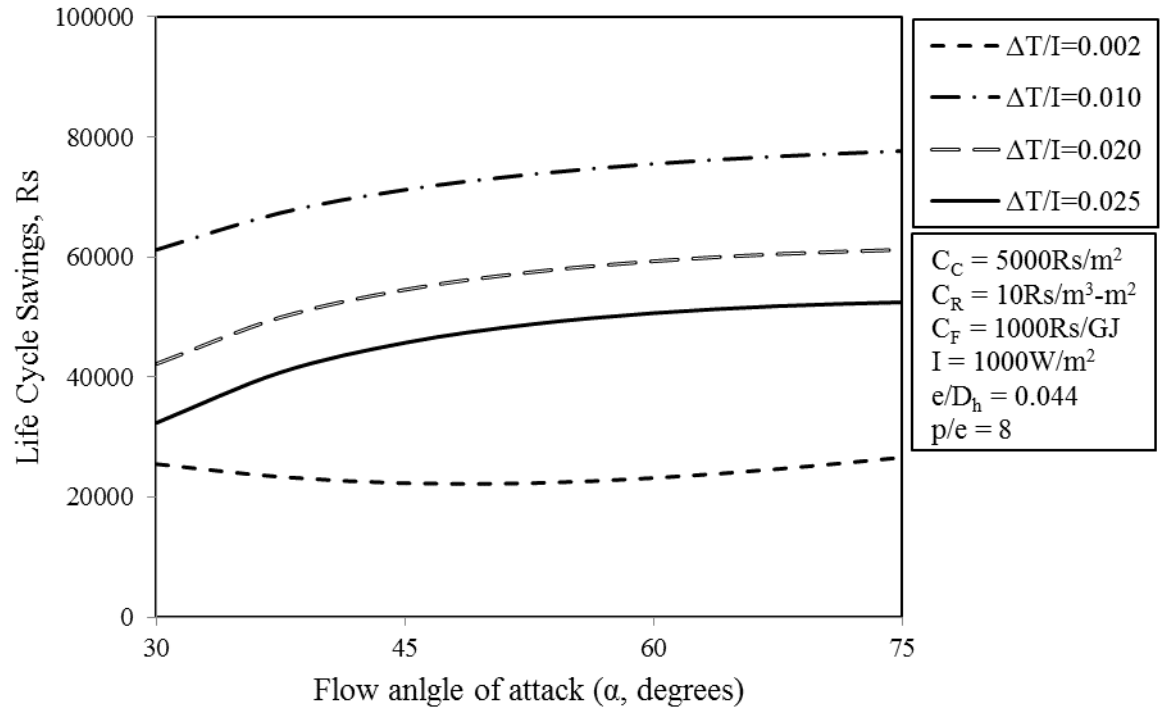

Figure 12. Variation of *LCS* with *α* for different *ΔT/I*.

Effect of Roughness Cost Factor on LCS

Higher cost of material and fabrication per unit volume of material results in substantially lower values of *LCS* and the results can be seen from Figures 13 and 14. It is thus evident that roughness elements cost are added to the collector cost, but these are function of roughness parameters too. The maximum *LCS* is obtained for the lowest value of C_R of 2, and as C_R increases from 2 to 20, the values of *LCS* decreases. Another interesting outcome of variation of *LCS* with C_R is seen in Figure 14, where it is evident that the *LCS* has a linear variation with values of C_R for a particular value of *ΔT/I*. this is mainly since as C_R increases the cost of the collector increases thereby increasing the initial investment costs, which in turn decreases the *LCS*.

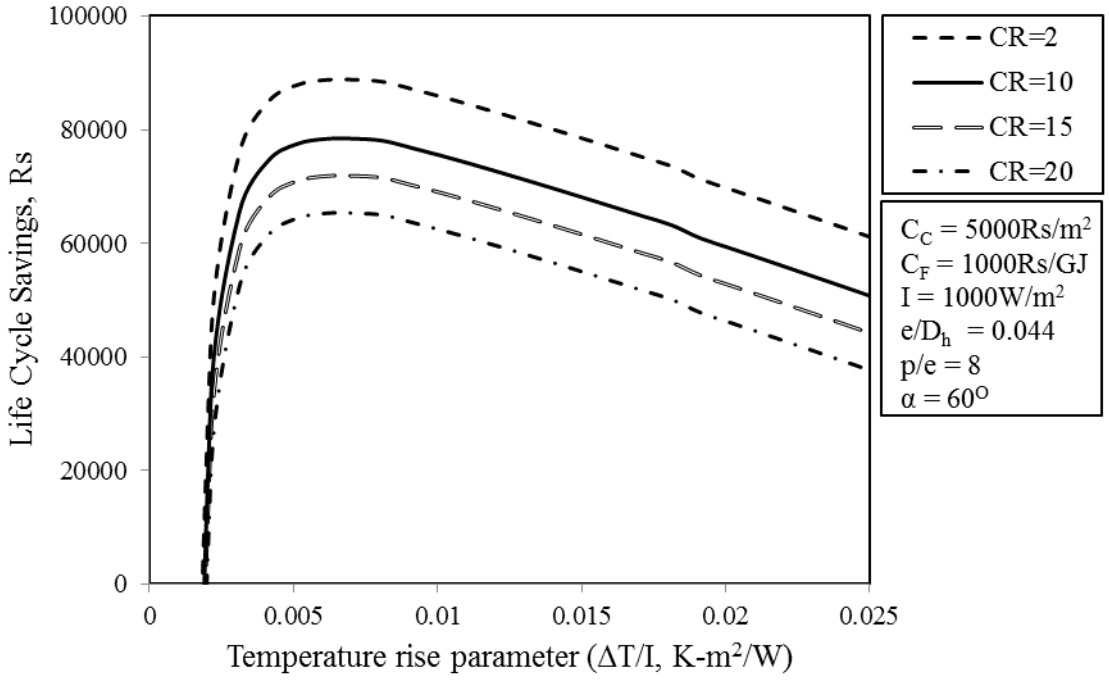

Figure 13. Variation of *LCS* with *ΔT/I* for different C_R.

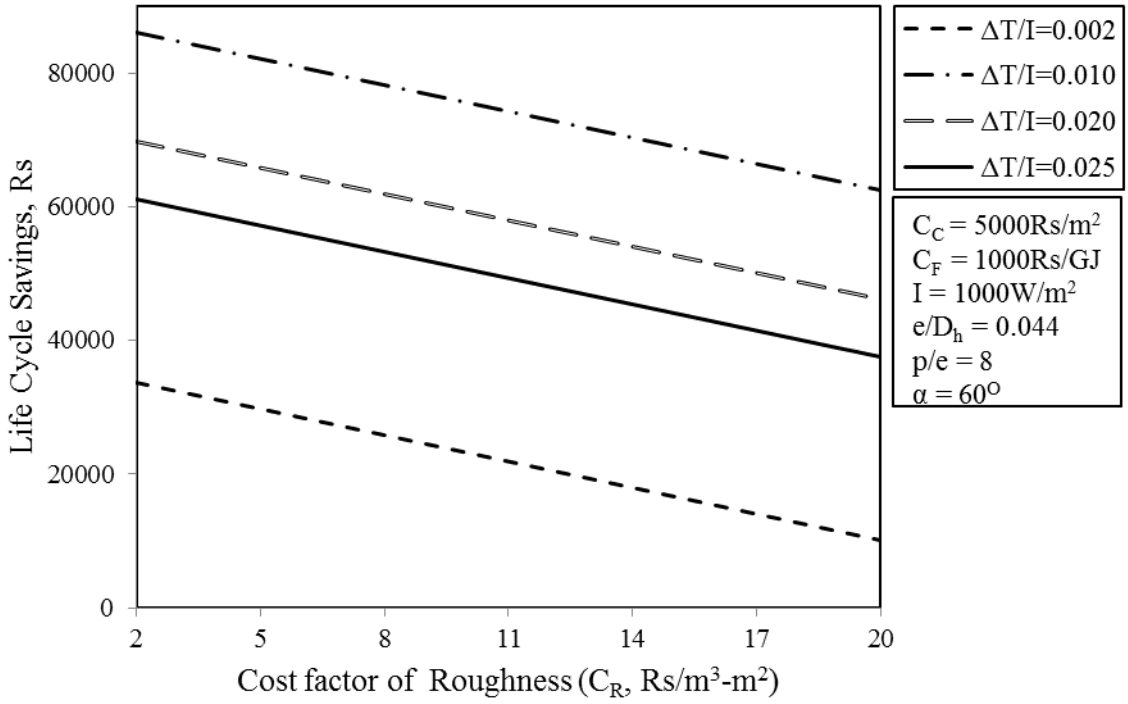

Figure 14. Variation of *LCS* with C_R with different *ΔT/I.*

Effect of Cost Factor of Conventional Fuel on LCS

To study the effect of C_F on *LCS*, plots of *LCS* for different values of the C_F are presented in Figures 15 and 16. It is clearly seen that the *LCS* is a strong function of C_F and it increases substantially with an increase in C_F. Maximum *LCS* is found for maximum value of C_F of 2000. This is attributed to the fact that as CF increases from 300 to 2000, the solar fuel savings increases, because for same amount of energy saved by solar energy, the cost of energy is high if that same amount of energy is utilized by convention fuel of high cost as compared to convention fuel of low cost. Hence higher values of C_F give better *LCS*. Also, from Figure 16, it is seen that the variation of LCS with CF is linear for a particular value of *ΔT/I.*

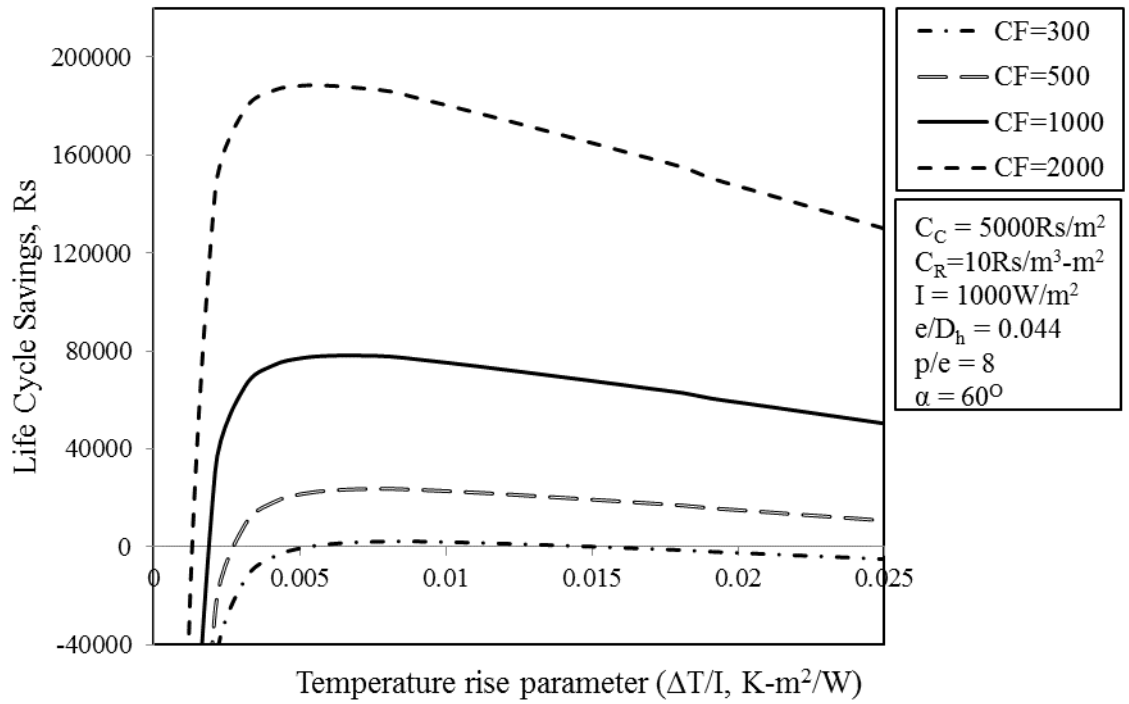

Figure 15. Variation of *LCS* with *ΔT/I* for different C_F.

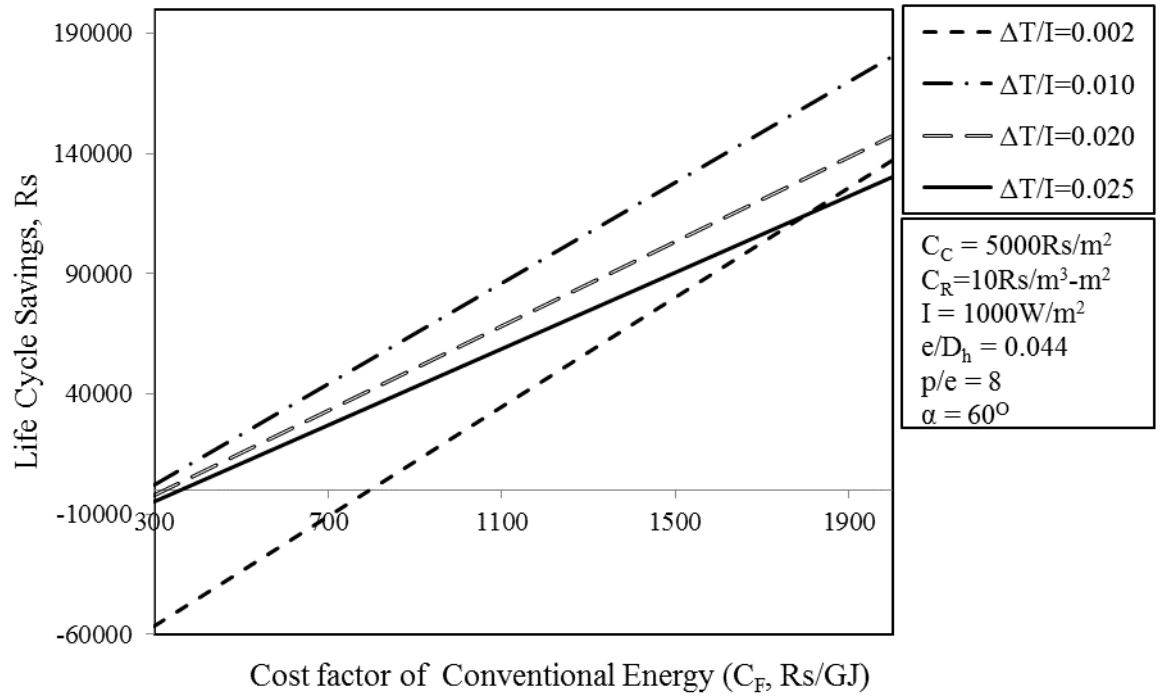

Figure 16. Variation of *LCS* with C_F with different *ΔT/I*.

Impact

The usage of solar air heaters in residential and commercial applications to replace traditional heaters is growing, garnering the attention of numerous investigators who are working to improve the efficiency of solar air heaters while lowering their installation and operating costs.

In the recent times, due to the increased cost of non-renewable energy resources, the financial aspect of using solar air heater has become more prominent. The investors will consider investing in solar air heater only if it is profitable in comparison to conventional air heaters, hence it is imperative to assess the economic viability of solar air heater before installing it for industrial and domestic use. The present research work deals exactly with this problem and gives designers the complete economic analysis of an artificially roughened solar air heater with v-shaped ribs for different system and variable parameters.

From the results of economic analysis, it can be stated that there exists a set of optimum values of roughness parameters which maximizes the life cycle savings of a SAH, and this set of parameters comprising of e/D_h, p/e, and α, is a strong function of operating parameters namely $\Delta T/I$ and I and the economic parameters, namely C_C, C_R and C_F. For lower values of $\Delta T/I$ the 0.020 value e/D_h, 12 value of p/e and 30° of α gives highest values of *LCS*. Whereas for higher values of $\Delta T/I$ the 0.044 value e/D_h, 10 value of p/e and 75° of α gives highest values of *LCS*. Also, the best values of C_C, C_R and C_F for which maximum *LCS* is obtained are 1000, 2, and 300 respectively.

Moreover, through this research, the designers now have a vast data of economic analysis for different system and variable parameters of solar air heater with v-shaped ribs, which is very scarce in this field. Hence the use of solar air heater is expected to increase after this research work thereby increasing the share of solar energy in the global energy mix and reducing carbon emission from conventional fuel combustion for air/space heating; also facilitating the saving of natural resources.

It should also be noted that the installation of a solar air heater, which will be used for drying or space heating, assumes the availability of appropriately qualified personnel, which will result in the creation of new jobs, the number of which depends on the scale of implementation, thus producing socio-economic impact too in the society.

Conclusions

Based on this work, the following conclusions have been drawn:

1. There is a strong effect of roughness parameters on *LCS* of an artificially roughened SAH. Maximum values of *LCS* obtained corresponds to the lowest value of e/D_h in the case of $\Delta T/I < 0.007$, whereas for $\Delta T/I > 0.007$ highest values of *LCS* is found for highest values of e/D_h.

2. The utmost *LCS* comes at *p/e* value of 12 for lower values of *ΔT/I* (less than 0.008), while the max *LCS* comes at a *p/e* value of 10 for larger values of *ΔT/I* (greater than 0.008).
3. C_C as well as C_R plays an important role in determining the *LCS* of an artificially roughened SAH. An increase in C_C and C_R values results in a substantially large decrease in *LCS.* Further, an increase of collector cost, as well as roughness cost beyond a certain limit, may result in negative *LCS*.
4. C_F is another promising parameter on which *LCS* of an artificially roughened SAH depends. With an increase in C_F, *LCS* increases.

Conflict of Interest

There are no conflicts to declare.

Acknowledgements

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THERMODYNAMIC ANALYSIS OF COMBINED ORC-VCR SYSTEM WITH RECUPERATOR AND REHEATER

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Highlight
The study evaluates the performance of modified ORC-VCR system for various refrigerants.

Abstract
The trend of utilization of low-grade thermal energy gain huge attention due to increase in energy demand and depletion of conventional resources of energy. Low grade energy can be used in ORC-VCR cycle for refrigeration purpose. In the present work, to improve the performance a modified ORC-VCR cycle, recuperator and reheater are integrated in the cycle. The thermodynamic analysis of the modified system has been conducted with R600a, R600, R290 and R1270 as working fluids under various operating conditions viz. evaporator temperature, condenser temperature, boiler exit temperature. Different parameters evaluated to assess the performance are overall COP, mass flow rate per kW cooling capacity, expansion ratio and compression ratio. From the analysis, butane is found as a best choice for the modified ORC–VCR cycle. It was found that for the modified ORC-VCR cycle at boiler exit temperature of 90°C and condenser temperature 40°C has system COP of 0.5542 with butane, which is 7.1% and 18% higher than that of ORC-VCR cycle with recuperator and simple ORC-VCR cycle, respectively.

Keywords
low grade energy; organic rankine cycle; refrigeration; hydrocarbons; recuperator; reheater.

Introduction
The trend of utilization of renewable energy gain huge attention due to increase in energy demand and depletion of conventional resources of energy. The countries should focusses on sustainable development and to asses it, Khanova et al. [1] proposes a multidimensional Sustainable Development Index. Various renewable resources of energy such as, wind, geothermal, solar and biomass can be used for electricity generation [2–4]. Heat exchangers is one of the main component used in various renewable and non-renewable device and its sustainability was assessed by Kumar et al. [5] for different types of nanoparticles using intuitionistic fuzzy combative distance-based assessment ($IFCODAS$) method and observed that Carbon based nano particles has more reliable and sustainable thermal systems. The waste heat and low-grade thermal energy can also be considered as renewable energy source and utilized in the electricity generation with the help of Organic Ranking Cycle (ORC) [6,7]. Organic Rankine cycle (ORC) is most suitable to recover low-grade thermal energy and can be applied with solar thermal devices, power plant where large amount of waste heat generated. In present context, ORC cycle has market share

of 48% in biomass, 31% in geothermal, 20% in waste heat recovery and 1% solar application [8]. Due to lack of awareness, ORC market share has not much augmented in solar appliances but has a huge potential.

Researchers always try to improve the performance of ORC using either different working fluid or different coupled system. Xu et al [9] presented a novel review on utilization of zeotropic fluids in ORC. They theoretically analyse the performance of different zeotropic fluid and recommended that zeotropic fluid have vast application in ORC. Andreasen et al [10] considered propane, i-butane, i-pentane, R1234yf and their blends as working fluid in ORC and observed that R1234yf is more economical than other working fluids. ORC cycle was coupled with liquid flooded expansion system using R1233zd(E) as working fluid by Li et al [11] in their experimental work. They pointed out that the liquid flooded expansion system improves the isothermal efficiency of expander, resulting in better performance of ORC cycle. An another modification was proposed by Chen et al [12], where they couple ORC with absorption heat pump and reported that coefficient of performance of absorption heat pump (COP) can be obtained from 1.38 to 2.37 depending upon the operating parameters. Recently, Kumar et al [13] utilizes solar flat plate collector for harnessing solar thermal energy as heat source to ORC and studies energetic end exergetic performance of ORC using MWCNT/R141b nano refrigerant. They found enhancement of 8.4% and 6.2% in energetic and exergetic efficiency, respectively.

In the present scenario, massive portion of the generated electricity is consumed by the refrigeration system [14]. Refrigeration effect can also be directly produced by waste thermal energy with the help of vapour absorption and ejector refrigeration system. However, such systems are only suitable when waste heat available in range of 100 to 200^{o}C and can produce refrigeration effect at higher temperature of 5^{o}C or more [15]. ORC-vapour compression refrigeration system (VCR) cycle is another way to produce refrigeration effect from low grade heat in range of 90 to 100^{o}C. In ORC-VCR cycle, waste heat is supplied in ORC to produce power and VCR cycle run by that power [16].

The ORC-VCR cycle consist working fluid with low NBP which is shared by both the cycles. In this system, compressor and expander are directly attached through shaft. The power generated by expander is utilized to run boiler feed pump of ORC and compressor of VCR. So far, several studied have been done on ORC-VCR cycle which reveals the overall performance of cycle is significantly affected by the working fluid. Li et al. [17] investigated ORC-VCR cycle with four hydrocarbons viz. R600, R290, R600a and R1270. Yue et al. [18] investigated ORC-VCR cycle with R134a, n- propane, cyclopentane, and R245fa and found R134a as best candidate. Rawat et al. [19] presented energy analysis of ORC-VCR cycle with hydrocarbons. Saleh [16] has performed the parametric study of ORC-VCR system and concluded R602 is the most suitable among fourteen fluids viz. R602, R601a, R601, R600, R600a, C5F12, RC318, R236fa, R152a, R236ea, R245fa, R245ca, R1234ze(E), RE245cb2. Pektezel et al. [20] proposed ORC-VCR cycle with single and dual evaporator and found that performance of the system decreased with extra evaporator.

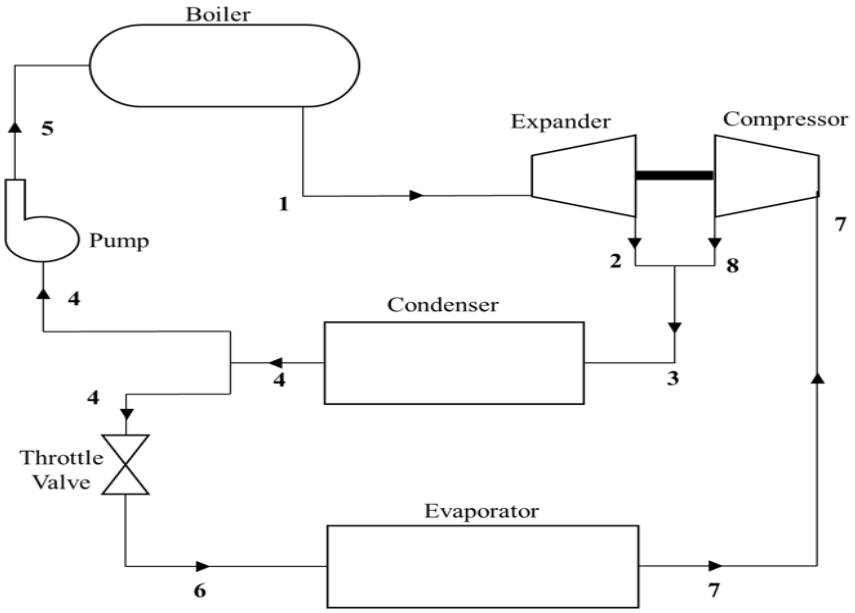

Figure 1. Schematic diagram of ORC-VCR system.

Nabati and Saadat-Targhi [21] proposed ORC-VCR cycle to produced cold water for hospital using solar energy. They concluded that R22 is more suitable working fluids among R134a, R143a, R11, R22, R500, and R600. More studies had been conducted on ORC-VCR cycle with CFCs, HCFCs, HFCs, HFOs and HCs as working fluids. However, CFC, HCFCs, HFCs have adverse impact on environment. On the other hand, natural refrigerants have excellent thermo-physical properties and environment friendly nature (zero ODP, low GWP) [22,23]. Several researchers also employed various optimization technique to improve the performance of ORC-VCR cycle [24–28]. Present study deals with modified ORC-VCR cycle using low-grade thermal energy. In the modified ORC-VCR cycle, recuperator and reheater are integrated to improve the performance. The thermodynamic analysis of the modified system has been conducted with R600a, R600, R290 and R1270 as working fluids under various operating conditions viz. evaporator temperature, condenser temperature, boiler exit temperature to determine their effect on the performance parameters viz overall COP, mass flow rate per kW cooling capacity, expansion ratio and compression ratio.

System Overview

Schematic illustration of the modified ORC–VCR system with recuperator and reheater is shown in the Figure 2. In system we have two cycles, first is power cycle (1-2-3-4-5-6-7-8-9-1) and the other is refrigeration cycle (7-10-11-12-7) both cycles share same refrigerant as a working fluid. This modified system has a recuperator and two expanders which are operating at same shaft speed and compressor is also directly coupled to this shaft. At outlet of the boiler, working fluid is in vapour phase which enters in first expender and pressure decrease up to intermediate pressure then again it is send to the boiler for reheating. After reheating, working fluid expands into second expander up to condenser pressure. Now working fluid enters in the recuperator which is a counter flow energy recovery heat exchanger. Recuperator is the placed between the second expander exit and the condenser inlet or between the pump exit and boiler inlet for heat recovery. In the recuperator liquid is preheated before entering the boiler by absorbing heat from the working fluid coming out from the second expander.

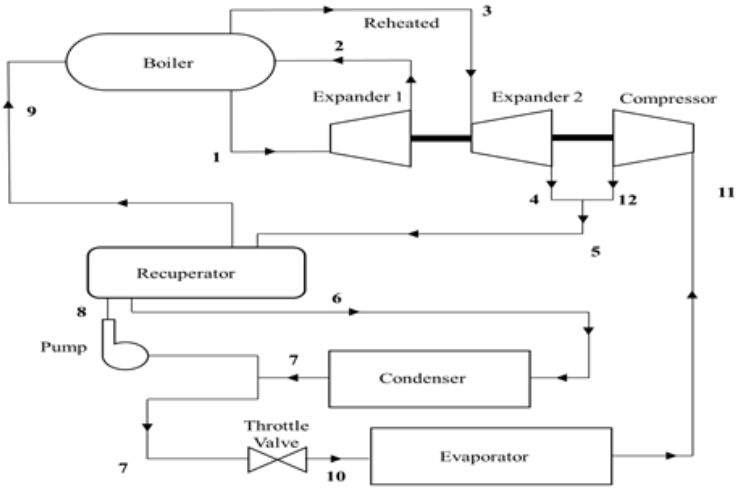

Figure 2. Schematic illustration of modified ORC-VCR system.

The T–S diagram of the modified ORC–VCR system is depicted in Figure 3. The different processes which describe the system are 1→2 actual expansion through the high pressure expander; 2→3 reheating at constant pressure; 3→4: actual expansion through the low pressure expander; 4→5: constant pressure cooling of low pressure expender vapour by mixing with compressor discharge vapor; 5→6: The expander exhaust is used to preheat the working fluid exiting the pump; 6→7: Isobaric heat rejection (condensation); 7→8: actual pumping work; 8→9. The working fluid is preheated by the expander exhaust; 9→1: Isobaric heat addition in the boiler; 7→10: isenthalpic expansion through the throttle valve in the VCR cycle; 10→11: Isobaric heat absorption (evaporation) in the VCR cycle; 11→12: actual compression through the compressor.

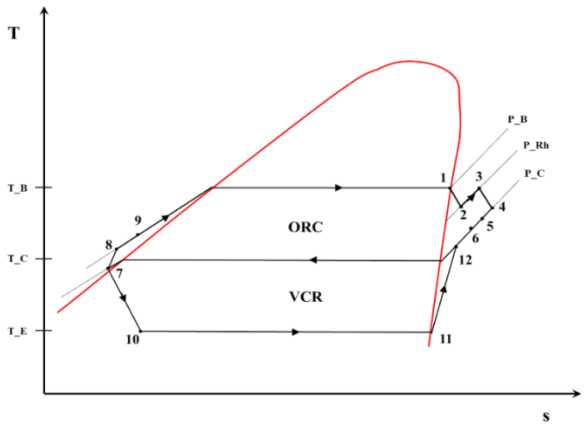

Figure 3. T-S diagram of the modified ORC-VCR System.

Methods

In the present work, thermodynamic analysis of modified ORC-VCR system has been carried by considering all components are in steady-state conditions and there are no heat & friction losses. The thermo-physical properties of the working fluids for different states have been calculated using a software package Energy equation solver (EES). Software EES is a vital tool for thermodynamic calculations of refrigeration and cryogenic systems [18,19].

Work obtained by the first expender

(1) $$\dot{w}_{E1} = \dot{w}_{1-2} = \dot{m}_{ORC}(h_1 - h_{2s})\eta_{exp1}$$

(2) $$\dot{w}_{E1} = \dot{m}_{ORC}(h_1 - h_2)$$

Heat supplied in the reheater

(3) $$\dot{Q}_{Re} = \dot{m}_{ORC}(h_3 - h_2)$$

Work obtained by the second expender

(4) $$\dot{w}_{E2} = \dot{w}_{3-4} = \dot{m}_{ORC}(h_3 - h_{4s})\eta_{exp2}$$

(5) $$\dot{w}_{E2} = \dot{m}_{ORC}(h_3 - h_4)$$

Recuperator

(6) $$(\dot{m}_{ORC} + \dot{m}_{VCR})(h_5 - h_6) = \dot{m}_{ORC}(h_9 - h_8)$$

The effectiveness (ε) is the ratio of the actual to maximum possible heat transfer rates and is expressed as

(7) $$\varepsilon = \frac{T_5 - T_6}{T_5 - T_8}$$

Heat rejected in condenser

(8) $$\dot{Q}_C = (\dot{m}_{ORC} + \dot{m}_{VCR})(h_6 - h_7)$$

Work supplied in Pump

(9) $$\dot{w}_P = \dot{w}_{7-8} = \dot{m}_{ORC}(h_{8s} - h_7)/\eta_{pump}$$
$$\dot{w}_P = \dot{m}_{ORC}(h_8 - h_7)$$

Heat supplied in boiler

(10) $$\dot{Q}_{Boiler} = \dot{m}_{ORC}(h_1 - h_9)$$

Network obtained from the ORC

(11) $$\dot{w}_{net} = \dot{w}_{E1} + \dot{w}_{E2} - \dot{w}_P$$

Total heat supplied to ORC

(12) $$\dot{Q}_{Supply} = \dot{Q}_{Boiler} + \dot{Q}_{Re}$$

Efficiency of ORC

(13) $$\eta_{ORC} = \frac{\dot{w}_{net}}{\dot{Q}_{Supply}}$$

Heat absorbed in the evaporator

(14) $$\dot{Q}_E = \dot{m}_{VCR}(h_{11} - h_{10})$$

Work supplied to the compressor

(15) $$\dot{w}_C = \dot{w}_{11-12} = \dot{m}_{VCR}(h_{12s} - h_{11})/\eta_{comp}$$
$$\dot{w}_C = \dot{m}_{VCR}(h_{12} - h_{11})$$

(16) $$COP_{VCR} = \frac{\dot{Q}_E}{\dot{w}_{net}}$$

Work supplied to the compressor of VCR = Net work obtained from ORC

(17) $$\dot{w}_C = \dot{w}_{net}$$

(18) $$COP_{system} = COP_{VCR} \times \eta_{ORC}$$

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The expansion ratio (EPR) across the expander is proportional to the expander size and has been evaluated by

(19) $$\mathrm{EPR} = \mathrm{V_1}/\mathrm{V_4}$$

While the compression ratio across the compressor is calculated by

(20) $$\mathrm{CMR} = \mathrm{P_{12}}/\mathrm{P_{11}}$$

The input parameters and boundary conditions are tabulated in Table 1. The maximum boiler exit temperature is set as 90°C, which corresponds to the heat source temperature of about 100°C. This temperature level can be easily achieved by flat-plate solar collectors or water-dominated geothermal energy.

Table 1. Input parameters and boundary conditions.

Parameters	**Boundary**	**Range**
Boiler exit temperature ($\mathrm{T_b}$)	80°C	60 - 90°C
Condenser temperature ($\mathrm{T_c}$)	40°C	30 - 55°C
Constant subcooling in condenser	3°C	
Evaporator temperature ($\mathrm{T_e}$)	5°C	-15 - 15°C
High pressure expander isentropic efficiency (η_{exp1})	0.80	-
Low pressure expander isentropic efficiency (η_{exp2})	0.80	-
Compressor isentropic efficiency (η_{comp})	0.80	-
Boiler feed pump isentropic efficiency (η_{pump})	0.75	-
Effectiveness of Recuperator (ε)	0.90	-
Working fluid mass flow rate in ORC ($\dot{\mathrm{m}}$)	1kg/s	-
Reheat exit temperature ($\mathrm{T_b}$)	-	60 - 90°C
Reheat pressure	$(\mathrm{P_e} * \mathrm{P_c})^{1/2}$	-

Results and Discussion

Figure 4(a) Illustrates the effects of the boiler exit (BE) temperature on the $\mathrm{COP_{system}}$. It can be observed that, $\mathrm{COP_{system}}$ of the modified ORC–VCR system increase with BE temperature. The increase in boiler temperature leads to rise in turbine inlet enthalpy. Moreover, to satisfy the constant turbine and compressor power, $\dot{\mathrm{m}}_{\mathrm{ORC}}$ value decreases. This results in lesser heat input to boiler and increased efficiency of ORC cycle. The increase in value of η_{ORC} enhances the $\mathrm{COP_{system}}$. As the BE temperature increase from 60 to 90°C, the $\mathrm{COP_{system}}$ increases by 90.92%, 103.01%, 123.04% and 125.8% for R1270, R290, R600a and R600, respectively. The maximum $\mathrm{COP_{system}}$ is reported for R600, owing to the higher critical temperature of this fluid. With the BE temperature at 90°C, the $\mathrm{COP_{system}}$ for the R600 case is 0.5542 which is greater than that of the R600a, R290 and R1270 cases by about 6.6%, 26.3% and 37.89, respectively.

Figure 4(b) shows the effect of BE temperature on the $\dot{\mathrm{m}}/\mathrm{Q_0}$ (flow rate mass per kW refrigeration capacity). $\dot{\mathrm{m}}/\mathrm{Q_0}$ decreases with the increase in BE temperature for all working fluids as work generated by the expanders increase. The lowermost flow rate is found for R600 and followed by R600a, R290 and R1270. $\dot{\mathrm{m}}/\mathrm{Q_0}$ is highest for R1270 at 90°C reaching to a value of 0.01869 kg/kW-s. This is due to reduction in $\dot{\mathrm{m}}_{\mathrm{ORC}}$ as stated in explanation of Figure 4(a).

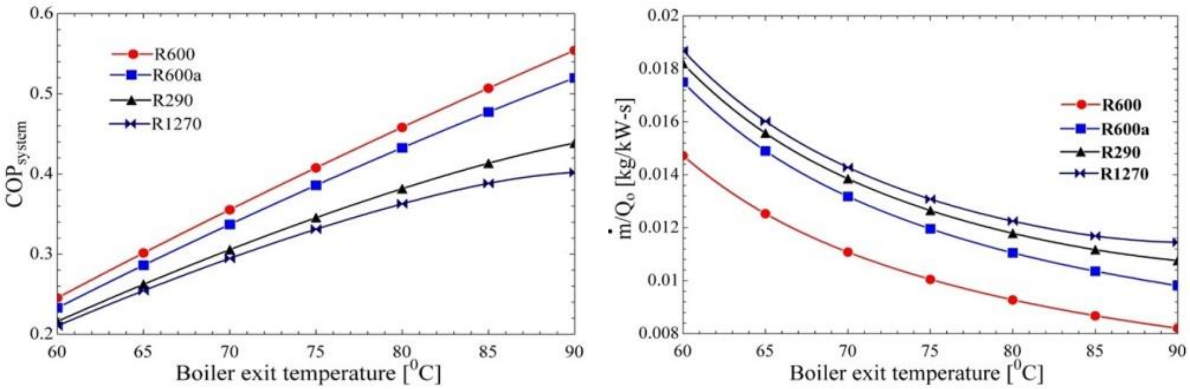


Figure 4. Variation of (a) $\mathrm{COP_{system}}$, (b) $\dot{m}/_{Q_0}$ with BE temperature.

The impact of BE temperature on the EPR is depicted in Figure 5(a). For increase in BE temperature with fixed condenser temperature, EPR in ORC increases, because with the increase in boiler temperature, saturation pressure also increases. EPR at the BE temperature at 90°C approximately three times that at 60°C for the wet refrigerants viz. R290 and R1270 and two times for dry refrigerants viz. R600 and R600a. The largest EPR is found in the case of R1270, followed by R290, R600, and R600a. However, it should be mentioned that the differences between EPR for these hydrocarbons are initially small, and the maximum appears at about 37.86% between the cycle of R600 and R1270 at boiler exit temperature of 90°C.

Condenser temperature has a major impact on ORC–VCR system performance, as illustrated in the Figure 5(b). In ORC-VCR system, condenser is shared by both cycles, and it also depends on the surrounding temperature. For fixed boiler and evaporator temperature, too high value of condenser temperature is undesirable. Also, it can be deduced from the plot that with increase in condensation temperature, the $\mathrm{COP_{system}}$ decreases. This is attributed to increase in exit enthalpy of turbine. Furthermore, to guarantee the constant turbine power, $\dot{\mathrm{m}}_{\mathrm{ORC}}$ must increase and η_{ORC} must decrease. On comprising different working fluid, R600 has shown better $\mathrm{COP_{system}}$ than R290, R600a and R1270. The $\mathrm{COP_{system}}$ of the ORC–VCR systems using R1270, R290, R600a and R600 as working fluids gives 0.1367, 0.1446, 0.1675 and 0.1821, respectively, at condensation temperature of 55°C.

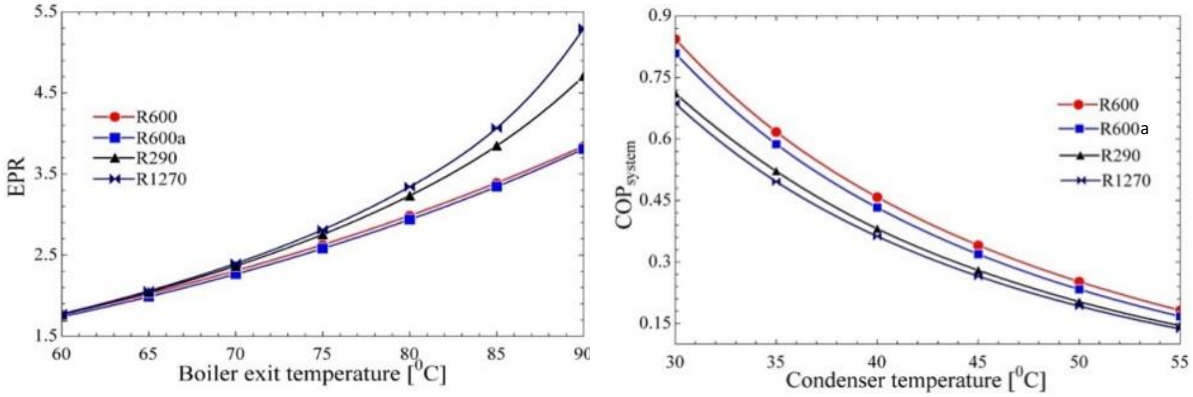
Figure 6(a) shows the variation of mass flow rate per kW cooling capacity with the condenser temperature. Increase in Condenser temperature causes an increase in the total mass flow rate per kW cooling capacity due to increase in $\dot{\mathrm{m}}_{\mathrm{ORC}}$. Under the same operating conditions, the lowest mass flow rate per kW cooling capacity is found in case of R600 with the value of 0.02113 kg/kW-s, whereas the highest occurs for R1270 reaching to 0.03076 kg/kW-s.

It is deduced from Figure 6(b) that, the EPR in the ORC decreases with increase in the condenser temperature. This is obvious taking when the thermo physical properties of these working fluids into consideration. Th differences among the expander ratio values for the four hydrocarbons are similar for 30 to 55°C condenser temperature. Comparing with the other fluids the decrement in the EPR in the cases of R1270 and R290a are more prominent. It is interesting to report that with the condenser temperature higher than 50°C, the differences among the EPR for dry hydrocarbons viz. R600 and R600a are quite small.

From Figure 7(a), it is observed that CMR value increase with condenser temperature as pressure ratio in the VCR cycle increases. However, the value of CMR significantly increase with condenser temperature for R600 and R600a. This is obvious due to thermo physical properties of the working fluids.

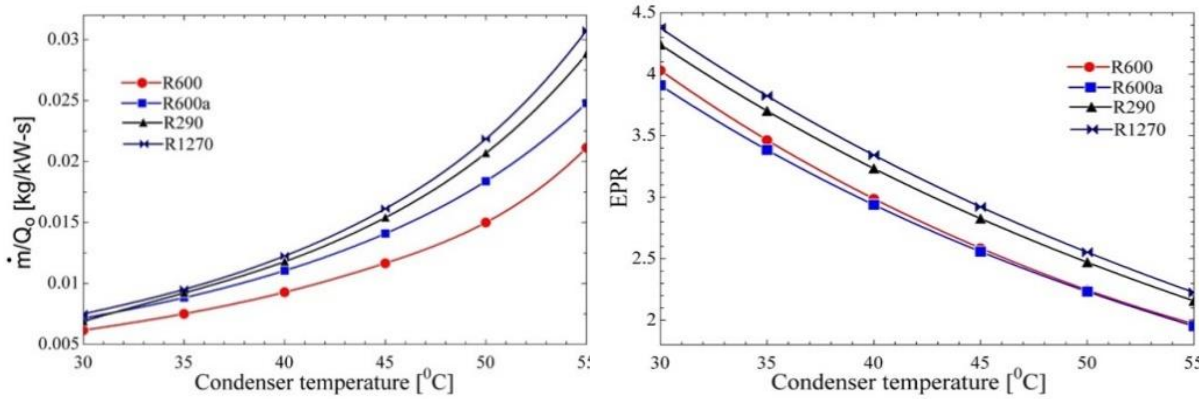
Figure 7(b) shows the effect of the evaporation temperature on the $\mathrm{COP_{system}}$. It can be observed that, as evaporation temperature increases, the $\mathrm{COP_{system}}$ of the ORC–VCR system also increases. The pressure ratio decreases therefore the compressor work decreases when evaporator temperature increases. This increases the COP of VCR system due to which the overall system performance enhances. As the evaporation temperature varies from -15 to 15°C, the $\mathrm{COP_{system}}$ increases by about 179.7% for the four cases. Moreover, under similar operating conditions, R600 case exhibits better performance. For example, with the evaporation temperature at

−15°C, the $\mathrm{COP}_{\mathrm{system}}$ of the ORC–VCR system using R600 is approximately 5.1%, 19.76% and 26.36% higher than the cases of R600a, R290 and R1270, respectively.



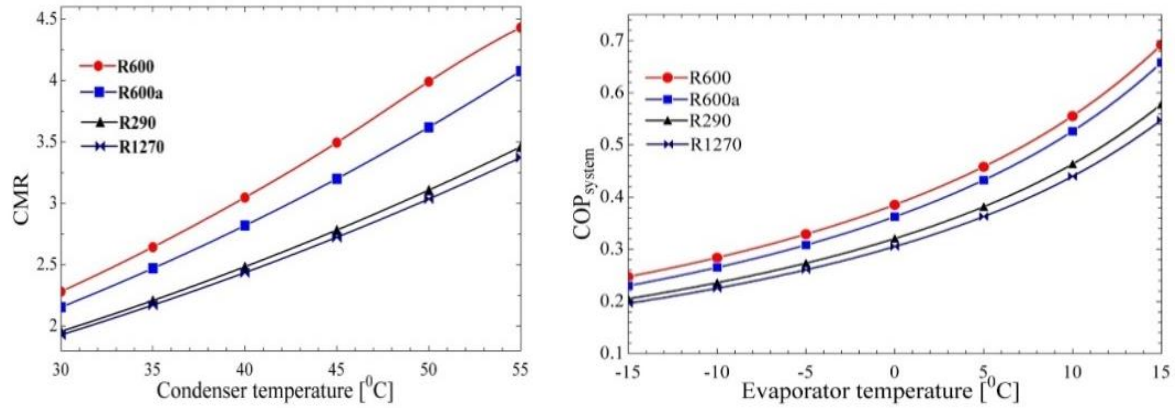
(a) (b)

Figure 5(a) Variation of EPR with BE temperature, (b) Variation of $\mathrm{COP}_{\mathrm{system}}$ with condenser temperature.



(a) (b)

Figure 6(a) Variation of condenser temperature with $\dot{m}/Q_0$, (b) Variation of condenser temperature with EPR.

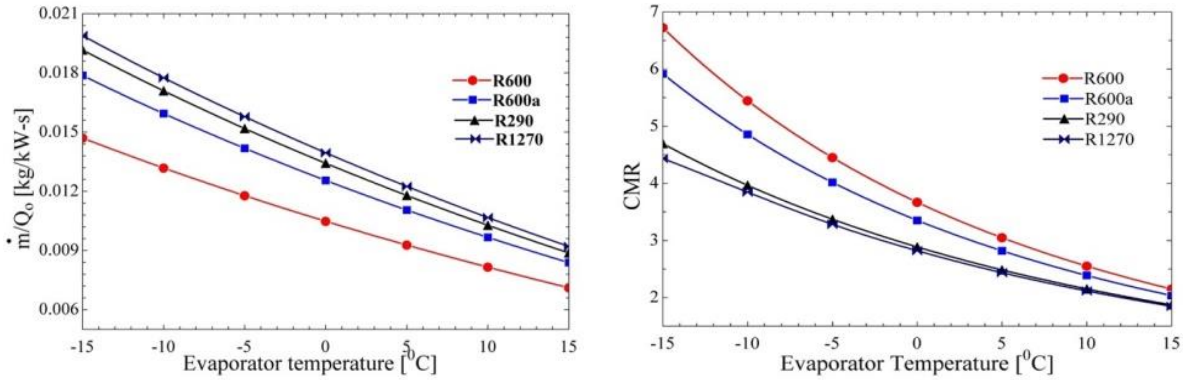


(a) (b)

Figure 7(a) Variation of CMR with condenser temperature, (b) Variation of $\mathrm{COP}_{\mathrm{system}}$ with evaporator temperature.

Figure 8(a) shows the variation of $\dot{m}/Q_0$ with the evaporator temperature. The value of $\dot{m}/Q_0$ decreases with the increase in evaporator temperature. This is because of decrease in compressor power and turbine power with increase in evaporator temperature. The decrease in turbine power results in decreases in $\dot{m}_{ORC}$. Therefore, $\dot{m}/Q_0$ for combined system also decreases. As the evaporator temperature varies from -15 to 15°C, the $\dot{m}/Q_0$ decreases and it is lowest for butane. Moreover, under similar operating conditions, R1270 a gives highest mass flow rate per kW cooling capacity. $\dot{m}/Q_0$ is about 17.8%, 24.79% and 29.43% lower than that of R600a R290 and R1270, respectively.

Figure 8(b) depicts the variation of evaporator temperature with CMR. As the evaporation temperature varies from -15 to 15°C, CMR decreases, and it is lowest for the propylene. Propane and propylene both are wet fluid refrigerants and their CMR are almost similar. On increasing evaporator temperature at fixed condenser temperature, the pressure ratio decreases, hence the size of compressor reduces.



(a) (b)

Figure 8(a)Variation of evaporator temperature with $\dot{m}/Q_0$, (b) Variation of CMR with evaporator temperature.

The performance of the modified ORC-VCR system with recuperator and reheater is also compared with simple ORC-VCR system with no additional component and ORC-VCR system with recuperator only in Figure 9. For the modified ORC-VCR cycle, at boiler exit temperature of 90°C and condenser temperature 40°C the system COP with butane is 0.5542 which is 7.1% and 18% higher than that of ORC-VCR cycle with recuperator only and simple ORC-VCR cycle, respectively.

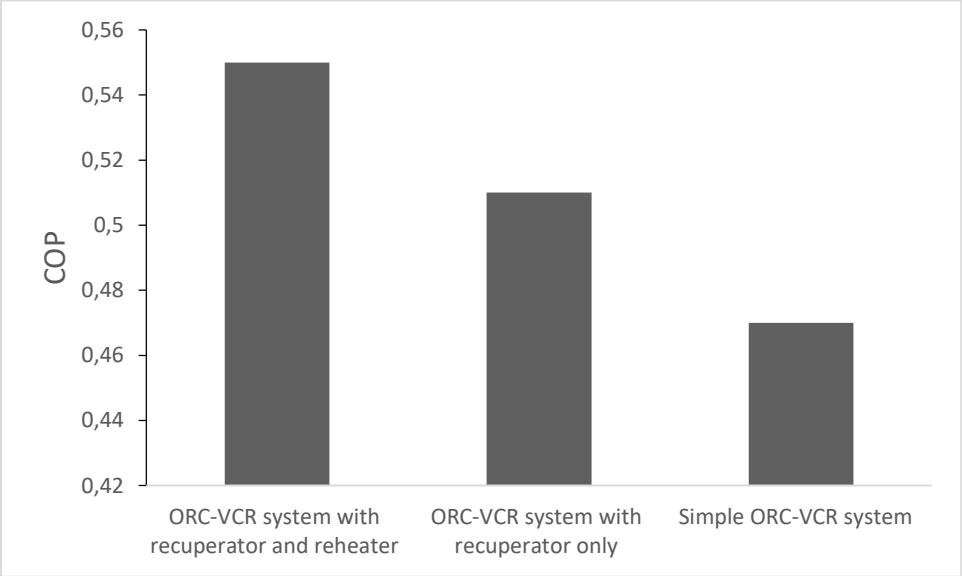


Figure 9 Comparison of COP for different configuration of ORC-VCR System.

Conclusions

In the present work, modified ORC-VCR cycle integrated with recuperator and reheater has been investigated using R600a, R600, R290 and R1270 as working fluids. From the analysis, effect of various operating conditions viz. evaporator temperature; condenser temperature; BE temperature on overall COP, mass flow rate per kW cooling capacity, expansion ratio and compression ratio are concluded here. The performance of modified ORC-VCR cycle with recuperator and reheater has shown favourable characteristics for R600 and R600a in comparison to R290 and R1270. Moreover, for same conditions, the performance of the modified ORC-VCR cycle is higher in comparison to simple ORC-VCR system and ORC-VCR cycle with recuperator.

Impact

The increase in demand for energy and depletion of conventional energy resources has led researcher to find either non-conventional energy resources or efficient conventional systems. The non-conventional energy resources have limited potential and still in developing phase. However, conventional system performance can be significantly improved by optimizing the working parameters and reducing the waste energy. The thermodynamic Organic Rankine cycle (ORC) has ability to utilize low grade thermal energy from either renewable sources or waste heat from power plant. ORC has been coupled with different systems like liquid flooded expansion system and absorption heat pump, vapour compression refrigeration system (VCR), and others to augments the performance. The present work focuses on improving the performance of ORC-VCR cycle by firstly integrating the recuperator and an intermediate reheater, and then operating parameters like refrigerant type, boiler exit temperature, and others are also optimized. Working fluids plays a crucial role in the ORC system's efficient functioning particularly in case of waste heat having low-grade temperature. From present study, the Butane as a working fluid in ORC-VCR system has yielded best performance among considered working fluid, so it is recommended for application in ORC-VCR cycles.

Conflict of interest

There are no conflicts to declare.

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A STUDY ON IMPACT OF OPEN INNOVATION OPENNESS ON THE PRACTICES ADOPTED BY INDIAN FOOD PROCESSING SMES ON PRODUCT INNOVATION OUTPUT

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Abstract
This study throws light on the outline of innovation taking place in Indian Food Processing SMEs with a special focus on open Innovation taking place in these SMEs and the exchange of information or knowledge taking place between inside-out and outside-in parties for the purpose of innovation. In addition, puts special focus on describing how SMEs' product innovation output related with the effect of outside-in and inside-out exchange of knowledge and information. Further, it analyzes how expenditure on innovation and collaborating with outside parties can help in the predicting product innovation output of Indian Food Processing SMEs. The analysis was done with the help of Jamovi to find out regression between the dependent variable- "Product innovation output" & independent variables- "Extent of openness", "Inhouse R& D expenditure", "Purchase of R&D from outside sources", "Acquiring knowledge from outside sources" and control variable- "Indian Food Processing SMEs". And towards the end, it contains the summary of the survey done, which suggested that Indian Food Processing SMEs are proactively involved themselves in inside R&D in comparison to the outside R&D and buying or taking license from outside sources. Other than these activities, one more pointer came as a takeaway from the study, product innovation is performed more in comparison to process innovation by the Indian Food Processing SMEs.

Keywords
open innovation; open innovation openness; product innovation; innovation output; India; food processing SMEs.

Introduction

Numerous researchers have already been doing innovation, from arranging a surprise party to a giving idea. It has always been in the form of involving friends and collecting ideas. It has gradually become bigger set-up, after emerging social media. In industries, no doubt closed innovation models were more controlled and worked well, but after the new management practices like delegation, collaboration and taking risk came within the culture of organizations. The only choice left is to move from closed to open innovation models. There are still many companies which are relying upon developing core strengths and developing and protecting their intellectual properties. Researchers suggest that it is not easy to set up open innovation. Open innovation is a systemic shift that wants to think many aspects of one's business to use it effectively. R&D alone cannot fully conduct open innovation. Other parts of the organization, in marketing, in business development,

functions like human and resource management, must get on board for it to work effectively. Formal documentation of open innovation helps but growing a culture that supports open innovation is equally important for its effectiveness [1]. “Open Innovation is about bridging internal and external resources and act on those opportunities” [2]. “Open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology” [3]. “Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. This paradigm assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology” [4]. Open innovation means treating innovation like anything else — something that can be bought and sold on the open market, not just produced, and used within the boundaries of the firm. Open innovation is using the market internal hierarchies to source and commercialize innovations.
Presently worldwide organizational leaders see collaboration as a key to innovation but achieving innovation targets using internal resources only has turned disbelief for most of them. Numerous of them realized that it is about harnessing external resources. Many corporates like P&G, IBM, Unilever, Reckitt Benckiser, and BMW etc. have opted for this way of innovation a long before, with seamless positive results. They have experienced fast processing, reduced cost, more innovative ideas under a roof and lessened launch time for any product [5]. Julian Keith Loren states that open innovation is as powerful as expanding the horizon for design capacities, strengthened commercialization and from here increasing profits. Open innovation as an idea for organizations is as near as it penetrates organizational walls, transforms business models and thus enabling a business to the edge and ahead of competitors [6]. Van de Vrande et al. [7] explored whether SMEs use open innovation approaches. Open innovation applies to a much larger number of SMEs than only MNEs. Focused on technological exploitation and indicated that many SMEs try to gain from their (non-R&D) employees' efforts and knowledge. When it comes to technological exploration, most SMEs aim to include their consumers in the process in some form, such as tracking product improvements, proactively incorporating them in market research, etc. Furthermore, acquiring new or missing information through external networking is a key open innovation activity for SMEs. Outward and inward IP licensing, venture capital, and external participation, on the other hand, are only used by a small percentage of SMEs. Customer interaction and external networking, for example, are informal, unstructured behavior that may not always necessitate large investments. Tranekjer and Knudsen [8] concentrated on two research questions: In the first place, who and why do outsiders contribute information for open innovation? What drives people and businesses to generate and freely share information that can benefit other (even competitive) innovators? As suppliers, providers participate in product development initiatives and gain from offering services (in the form of their own knowledge development and innovation efforts). The provider is usually a customer or a supplier of the receiver company, although not always. Pullen et al. [9] investigated whether network features contribute to high innovation performance, and his findings showed that a business-like attitude to networking and a closed approach to open innovation are associated to high innovation performance. Goal complementarity should be emphasized upon. Parida, Westerberg, and Frishammar [10] shed light on which open innovation initiatives SMEs might participate in to kickstart their own innovation efforts. Future research on the issue of open innovation should include innovation performance as a dependent variable, and inbound open innovation activities should have different effect patterns on the two components radical and incremental of innovation performance.

Indian MSMEs

For the developing economy of India, SMEs are the backbone and has majorly supported the growth. To India’s GDP SMEs has contributed 29.7%, gives employment to approx. 11 crore people and 49.66% to Indian exports and 45% to the manufacturing output. And during the COVID-19 pandemic, the Indian SMEs were worst affected as trade came to standstill and the supply chains were disturbed in the entire World. Unconventional support systems and initiatives were introduced and implemented during year 2020 by the Ministry of MSME. Few of these were-redefining the definition of SMEs, offering financial support system through fund of funds, developing IT infrastructure for offering answers to the problems faced by the SMEs and more. The money allocated under the Union Budget was doubled for MSMEs to ₹15,700 crore for 2021-22 year. Recently, Indian SMEs had the attention because Government of India has realized their important position in the economy. Even after remarkable contributions to India’s economy, SMEs continue to encounter several hurdles. One of them is to keep upgrading their technologies with the rapid changes taking place these days and then bearing the risk of these technologies becoming obsolete. To achieve the goals set under the Atmanirbhar Bharat, there is a dire need to go for strong, bold, and swift structural changes accompanied with modernizing the Indian SMEs. As per India’s Hon’ble Prime Minister, Narendra Modi ji—skill, reskill and upskill, SMEs need to work on upgrading their skills. Several studies by the research bodies and academic institutions have thrown light on the importance

of digital tools and how the same can be utilized by the Indian SMEs to further hike their incomes by 34%. India as a developing country has the capacity to acquire the position of a strong economic power, with the help and contribution of SMEs in production, exports to other countries, promoting the spirit of entrepreneurship and no doubt, generating employment. Government of India has announced their budget for the year 2021 under which consideration has been given to the upliftment of SMEs sector and special focus has been put on their growth.

India improved its ranking from 81 in 2015 to 48 in 2020, marking the first time since the Global Innovation Index's establishment in 2007 that India has reached the top 50 inventive countries. According to the Economic Survey 2020-21, India ranks first in Central and South Asia and third among lower middle-income nations. According to the Economic Survey 2020-21, India must put more emphasis on innovation to propel itself to a higher growth trajectory and become the third biggest economy in terms of GHDP current US$ soon. This will need increasing gross R&D spending from its present level of 0.7 percent of GDP to at least the average level of Gross Domestic Expenditure on (GERD)in other top ten nations (GDP current US$). According to the Economic Survey 2020-21, the government sector accounts for a disproportionately big amount of total GERD, accounting for three times the average of comparable large countries. However, the contribution of the private sector to GERD is among the lowest in India. The contribution of the private sector to overall R&D staff and researchers is similarly lower than in other big economies. Despite having more flexible tax incentives for innovation than other economies, this condition has endured. For its amount of access to equity capital, India's innovation score is far lower than projected. This emphasizes the necessity for India's business sector to increase R&D spending. For its amount of access to equity funding, India's performance on Innovations has been lower than predicted. The Economic Survey 2020-21 emphasized the need to increase the contribution of the business sector to total GERD from the present 37 percent to close to 68 percent. According to the survey, the sectors' overall R&D contribution should be increased from 30 percent and 34 percent research personnel, respectively, to 58 percent and 53 percent, respectively [11].

Entrepreneurs, according to the vision of the Hon'ble Prime Minister, Shri Narendra Modi, are the foundation of the social change that India aspires to, and their efforts will lay the foundation for a New India, fill in the gaps in solutions required by the people, and help build the foundation for constructing a powerful India's economic structure. The Ministry of Micro, Small and Medium Enterprises is working to enable MSMEs to put their thinking caps on and create innovative solutions as part of the #IdeasforNewIndiaChallenge2020, while also looking for local solutions to local problems, which could be the generation leap India needs to transform its social, cultural, and economic ecosystem into a world leader. Under the Office of Development Commissioner – MSME's initiative for Support for Entrepreneurial and Managerial Development of MSMEs via Incubators, ideas for a New India are being sought from innovators, start-ups, technocrats, students, and MSMEs from all over India. And each accepted concept would receive monetary support of up to Rs. 15 lakhs [12].

Objectives and Research Methodology

Following are few tables throwing light on the Indian Food Processing SMEs:

Table 1. Gross value added (GVA) by food processing industries (FPI) at constant 2011-2012 prices (₹ in lakh crore).
Source: Annual Survey of Industries (ASI 2016-17).

Gross value added (GVA) by food processing industries (FPI) at constant 2011-2012 prices (₹ in lakh crore)							
S. No.	Economic Activity	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
1	GVA-All India	90.64	97.12	104.92	113.28	120.74	128.03
2	Percentage share of food processing in GVA-Manufacturing	8.34	7.96	8.46	8.71	8.72	8.98
3	Percentage share of food processing in GVA-Agriculture, Forestry and Fishing	8.09	8.34	9.96	10.37	10.45	11.11

Table 2. Key features of registered food processing industries. *Source: Annual Survey of Industries (ASI 2016-17).*

Key features of registered food processing industries						
Rank	Total No. of Factories	No. of Factories in Operation	Fixed Capital	Total Persons Engaged	Output	Gross Value Added
1	Food Products (15.95%)	Food Products (16.78%)	Basic Metals (20.54%)	Food Products (11.36%)	Food Products (14.09%)	Coke & Refined Petroleum Products (12.87%)
2	Other Non-Metallic Mineral Products (11.92%)	Other Non-Metallic Mineral Products (12.13%)	Other Industries (13.34%)	Textiles (10.46%)	Coke & Refined Petroleum Products (12.06%)	Chemicals & Chemical Products (9.95%)
3	Textiles (7.54%)	Fabricated Metal Products, except Machinery and Equipment (7.33%)	Coke & Refined Petroleum Products (12.88%)	Wearing Apparel (7.63%)	Basic Metals (11.53%)	Basic Metals (8.12%)
4	Fabricated Metal Products (7.46%)	Textile (7.02%)	Chemicals & Chemical Products (8.96%)	Other Non-Metallic Mineral Products (7.24%)	Chemicals & Chemical Products (8.02%)	Motor Vehicles, Trailers & Semi-Trailers (7.68%)
5	Rubber & Plastic Products (5.97%)	Rubber & Plastic Products (5.70%)	Other Non-Metallic Mineral Products (6.16%)	Motor Vehicles, Trailers & Semi-Trailers (6.62%)	Motor Vehicles, Trailers & Semi-Trailers (7.74%)	Food Products (7.60%)
Aggregate Total (all industries)	234865	194380	319038649	14911189	726551423	136805049

Table 3. Employment in food processing industry. *Source: Annual Survey of Industries 2017-18, NSSO Report No. 582 (73/2.34/2) on Economic Characteristics of Unincorporated Non-Agricultural Enterprise, NSSO 73 Round (July 2015-June 2016)*

Employment in food processing industry			
Sector	Food Processing Industry	Overall Industry	(%) Share of Food Processing sector
Registered (2017-18)	19.33 lakh	156.14 lakh	12.38
Un-incorporated (2015-16)	51.11 lakh	360.41 lakh	14.18

Table 4. Sub – sector wise key parameters of registered food processing industries (₹ in crore)**.**
Source: ASI (2016-17).

Sub – sector wise key parameters of registered food processing industries (₹ in crore)									
Code (4 digits NIC, 2008)	Items	No. of Factories	No. of Persons Engaged	Fixed Capital (FC)	Total Output	Total Input	GVA	FC per Factory	GVA% (GVA / Input)
1010	Processing and preserving of meat	181	29812	2794	24846	23088	1758	15.43	7.62
1020	Processing and preserving of fish, crustaceans, mollusks, and products thereof	535	70298	4502	38388	3411	34977	8.41	9.75
1030	Processing and preserving of fruit and vegetables	1254	80440	8108	21830	4759	17070	6.47	27.88
1040	Manufacture of vegetable and animal oils and fats	3112	97888	17890	204537	196832	7705	5.75	3.91
1050	Manufacture of dairy products	2039	171497	22429	153260	140769	12491	11	8.87
1061	Manufacture of grain mill products	18899	345200	22769	253775	235801	17975	1.2	7.62
1062	Manufacture of starches and starch products	629	27352	5100	11266	9696	1570	8.11	16.19
1071	Manufacture of bakery products	1767	113043	5955	25704	20245	5459	3.37	26.96
1072	Manufacture of sugar	741	227890	62505	100672	83376	17296	84.35	20.74
1073	Manufacture of cocoa, chocolate and sugar confectionery	594	46253	8572	17898	13390	4508	14.43	33.67
1074	Manufacture of macaroni, noodles, couscous and similar farinaceous products	118	10048	2224	3267	2517	750	18.85	29.79
1075	Manufacture of prepared meals and dishes	323	27347	1215	7196	2820	4376	3.76	155.16
1079	Manufacture of other food products n.e.c.	6300	387742	22749	111557	93371	18186	3.61	19.48
1080	Manufacture of prepared animal feeds	976	58927	7150	49686	45993	3693	7.33	8.03
1101	Distilling, rectifying and blending of spirits; ethyl alcohol production from fermented materials	414	57760	12247	29491	23246	6245	29.58	26.87
1102	Manufacture of wines	77	6981	833	3359	2522	837	10.81	33.19
1103	Manufacture of malt liquors and malt	123	29471	6145	12303	9419	2884	49.96	30.61
1104	Manufacture of soft drinks; production of mineral waters and other bottled waters	1658	65903	12859	25955	18460	7495	7.76	40.6
TOTAL		39740	1853852	226045	1094990	973592	121397	5.69	12.47

Table 5. Indian's share in global food trade. *Source: ITC Trade Map, April 2019 (US$ Million.*

Indian's share in global food trade					
	2014	2015	2016	2017	2018
World food export	1448249	1304999	1325686	1433363	1471089
World food import	1459121	1333359	1336423	1445982	1505428
India's food export to world	37744.21	30417.56	29199.88	34434.32	34023.88
India's food import from world	19284.52	20783.16	21939.09	25064.67	19561.08
% Share of India's food export in world	2.61%	2.33%	2.20%	2.40%	2.31%
% Share of India's food import in world	1.32%	1.56%	1.64%	1.73%	1.30%

Table 6. Year – wise fixed capital deployment in registered factories in Food Processing Industries.

Year-wise fixed capital deployment in registered factories in Food Processing Industries	
Year	Fixed Capital (₹ in crore)
2010-11	120705
2011-12	145038
2012-13	158865
2013-14	168380
2014-15	191984
2015-16	206339
2016-17	226043
201718	245063

Table 7. FDI equity inflow to FPI. *Source: Department for Promotion of Industry and Internal Trade.*

FDI equity inflow to FPI			
S. No.	Year (April-March)	FDI (In ₹crore)	FDI (US$ Million)
1	2010-11	860.99	188.67
2	2011-12	859.02	170.21
3	2012-13	2,193.65	401.46
4	2013-14	25,106.77	3,982.89
5	2014-15	3,164.72	515.86
6	2015-16	3,312.00	505.88
7	2016-17	4,865.85	727.22
8	2017-18	5,835.62	904.9
9	2018-19	4,430.44	628.24
10	2019-20	3,241.76	463.44

After Focused Group Discussion with 28 experts from the Indian Food Processing Industry, survey method was adopted to study the objectives of innovation in Indian Food Processing SMEs, activities related to innovation in these SMEs. A structured questionnaire based on the feedback received from industry experts was adopted and modified to examine research objectives. The constructed tool used is -Innovation Survey of Indian Food Processing SMEs
https://docs.google.com/forms/d/e/1FAIpQLSfDS1ld_g6US9l1Kk-hlo0bpEE8QVStG8YEFjXWUkzI-d1A8g/viewform

Innovation Survey of Indian Food Processing SMEs

a. this survey collects information on your enterprise's innovations and innovation activities between 2016 and 2020 inclusive.
b. an innovation is the introduction of a new or significantly improved product, process, organizational method, or marketing method by your enterprise. The innovation must be new to your enterprise, although it could have been originally developed by other enterprises.
   The questions on innovation activities only refer to product and process innovations.
   Please complete all questions, unless otherwise instructed.
   Person we should contact if there are any queries regarding the form:
c. name: ……
d. job title: ……
e. organization: ……
f. phone: ……..
g. fax: ……..
h. e-mail: ……

1. General information about the enterprise
   - Name of enterprise
   - Address1
   - Postal code

   1.1. In 2016-20, was your enterprise part of an enterprise group? (A group consists of two or more legally defined enterprises under common ownership. Each enterprise in the group can serve different markets, as with national or regional subsidiaries, or serve different product markets. The head office is also part of an enterprise group.) Yes/No

   In which country is the head office of your group located? ……HO
   If your enterprise is part of an enterprise group: Please answer all further questions only for the enterprise for which you are responsible in [your country]. Exclude all subsidiaries or parent enterprises.

   1.2. In which geographic markets did your enterprise sell goods and/or services during the three years 2016-19?

A. Local / regional within [your country]	Yes	No
B. National (other regions of [your country])	Yes	No
C. All other countries	Yes	No

2. Product (good or service) innovation
   A product innovation is the market introduction of a new or significantly improved good or service with respect to its capabilities, user friendliness, components or sub-systems.
   - product innovations (new or improved) must be new to your enterprise, but they do not need to be new to your market
   - product innovations could have been originally developed by your enterprise or by other enterprises

   2.1. During the four years 2016 to 2020, did your enterprise introduce:

New or significantly improved goods. (Exclude the simple resale of new goods purchased from other enterprises and changes of a solely aesthetic nature.)	Yes	No
New or significantly improved services.	Yes	No

   If no to both options, go to section 3, otherwise:

   2.2. Who developed these product innovations?
   Select the most appropriate option only
   - mainly your enterprise or enterprise group
   - mainly your enterprise together with other enterprises or institutions
   - mainly other enterprises or institutions

2.3. Were any of your product innovations during the three years 2016 to 2020:

New to your market? Your enterprise introduced a new or significantly improved good or service onto your market before your competitors (it may have already been available in other markets)	Yes	No
Only new to your firm? Your enterprise introduced a new or significantly improved good or service that was already available from your competitors in your market	Yes	No

2.4. Using the definitions above, please give the percentage of your total turnover in 2020 from:
- new or significantly improved goods and services introduced during 2016 to 2020 that were new to your market …… %
- new or significantly improved goods and services introduced during 2016 to 2020 that were only new to your firm ……%
- goods and services that were unchanged or only marginally modified during 2016 to 2020 (include the resale of new goods or services purchased from other enterprises) …… %
- total turnover in 2020 - …… %

3. Process innovation
- a process innovation is the implementation of a new or significantly improved production process, distribution method, or support activity for your goods or services
- process innovations must be new to your enterprise, but they do not need to be new to your market
- the innovation could have been originally developed by your enterprise or by other enterprises
- exclude purely organizational innovations – these are covered in section 8

3.1. During the three years 2016 to 2020, did your enterprise introduce:

New or significantly improved methods of manufacturing or producing goods or services.	Yes	No
New or significantly improved logistics, delivery or distribution methods for your inputs, goods or services	Yes	No
New or significantly improved supporting activities for your processes, such as maintenance systems or operations for purchasing, accounting, or computing.	Yes	No

If no to all options, go to section 4, otherwise:

3.2. Who developed these process innovations?
Select the most appropriate option only
- mainly your enterprise or enterprise group
- mainly your enterprise together with other enterprises or institutions
- mainly other enterprises or institutions

3.3. Were any of your process innovations introduced between 2016 to 2019 new to your market?
- yes
- no
- do not know

4. Ongoing or abandoned innovation activities for process and product innovations
Innovation activities include the acquisition of machinery, equipment, software, and licenses; engineering and development work, industrial design, training, marketing and R&D when they are specifically undertaken to develop and/or implement a product or process innovation. Also include basic R&D as an innovation activity even when not related to a product and/or process innovation.

4.1. During 2016 to 2020, did your enterprise have any innovation activities that did not result in a product or process innovation because the activities were:

Abandoned or suspended before completion	Yes	No
Still ongoing at the end of the 2020	Yes	No

If your enterprise had no product or process innovations or innovation activity during 2016 to 2020 (no to all options in questions 2.1, 3.1, and 4.1), go to section 8.
Otherwise, go to section 5.

5. Innovation activities and expenditures for process and product innovations

5.1. During the three years 2016 to 2019, did your enterprise engage in the following innovation activities:

In-house R&D Creative work undertaken within your enterprise to increase the stock of knowledge for developing new and improved products and processes (include software development in-house that meets this requirement)	Yes	No

If yes, did your enterprise perform R&D during 2016 to 2020: Continuously (your enterprise has permanent R&D staff in-house)

External R&D Same activities as above, but performed by other enterprises (including other enterprises or subsidiaries within your group) or by public or private research organizations and purchased by your enterprise	Yes	No
Acquisition of machinery, equipment and software-Acquisition of advanced machinery, equipment and computer hardware or software to produce new or significantly improved products and processes	Yes	No

Acquisition of external knowledge

Purchase or licensing of patents and non-patented inventions, expertise, and other types of knowledge from other enterprises or organizations for the development of new or significantly improved products and processes	Yes	No
Training for innovative activities Internal or external training for your personnel specifically for the development and/or introduction of new or significantly improved products and processes	Yes	No
Market introduction of innovations-Activities for the market introduction of your new or significantly improved goods and services, including market research and launch advertising	Yes	No
Other activities to implement new or significantly improved products and processes such as feasibility studies, testing, routine software development, tooling up, industrial engineering, etc.	Yes	No

5.2. Please estimate the amount of expenditure for each of the following four innovation activities in 2020 only. (Include personnel and related costs)
If your enterprise had no expenditures in 2020, please fill in '0'
- in-house R&D (Include capital expenditures on buildings and equipment specifically for R&D) ……
- purchase of external R&D ……..
- acquisition of machinery, equipment and software (Exclude expenditures on equipment for R&D) ……..
- acquisition of external knowledge ……
- total of these four innovation expenditure categories ……..

5.3. During the three years 2016 to 2020, did your enterprise receive any public financial support for innovation activities from the following levels of government? Include financial support via tax credits or deductions, grants, subsidized loans, and loan guarantees. Exclude research and other innovation activities conducted entirely for the public sector under contract.

Local or regional authorities	Yes	No
Central government	Yes	No
Any International body/ organization	Yes	No

6. Sources of information and co-operation for innovation activities

6.1. During the three years 2016 to 2020, how important to your enterprise's innovation activities were each of the following information sources? Please identify information sources that provided information for innovation projects or contributed to the completion of existing innovation projects. Degree of importance Tick 'not used' if no information was obtained from a source. Mark as - High/Medium/ Low/ Not used

Internal Within your enterprise or enterprise group	High	Medium	Low	Not used

Market sources

Suppliers of equipment, materials, components, or software	High	Medium	Low	Not used
Clients or customers	High	Medium	Low	Not used
Competitors or other enterprises in your sector	High	Medium	Low	Not used
Consultants, commercial labs, or private	High	Medium	Low	Not used
R&D institutes	High	Medium	Low	Not used

Institutional sources

Universities or other higher education institutions	High	Medium	Low	Not used
Government or public research institutes	High	Medium	Low	Not used

Other sources

Conferences, trade fairs, exhibitions	High	Medium	Low	Not used
Scientific journals and trade/technical publications	High	Medium	Low	Not used
Professional and industry associations	High	Medium	Low	Not used

6.2. During the four years 2016 to 2020, did your enterprise co-operate on any of your innovation activities with other enterprises or institutions? Innovation cooperation is active participation with other enterprises or non-commercial institutions on innovation activities. Both partners do not need to commercially benefit. Exclude pure contracting out of work with no active co-operation.
Yes/No (Please go to question 7.1)

6.3. Please indicate the type of innovation co-operation partner by location (Tick all that apply)
Type of co-operation partner
i. your country
ii. any other countries

Other enterprises within your enterprise group	i	ii
Suppliers of equipment, materials, components, or software	i	ii
Clients or customers	i	ii
Competitors or other enterprises in your sector	i	ii
Consultants, commercial labs, or private R&D institutes	i	ii
Universities or other higher education institutions	i	ii
Government or public research institutes	i	ii

6.4. Which type of co-operation partner did you find the most valuable for your enterprise's innovation activities? Give corresponding mail/letter

7. Innovation objectives during 2016-2020

7.1. How important were each of the following objectives for your activities to develop product (good or service) or process innovations between 2016-2020?
If your enterprise had several projects for product and process innovations, make an overall evaluation on High/Medium/ Low/ Not used

Increase range of goods or services	High	Medium	Low	Not used
Replace outdated products or processes	High	Medium	Low	Not used
Enter new markets	High	Medium	Low	Not used
Increase market share	High	Medium	Low	Not used
Improve quality of goods or services	High	Medium	Low	Not used
Improve flexibility for producing goods or services	High	Medium	Low	Not used
Increase capacity for producing goods or services	High	Medium	Low	Not used
Improve health and safety	High	Medium	Low	Not used
Reduce labor costs per unit output	High	Medium	Low	Not used

8. Organizational innovation

An organizational innovation is a new organizational method in your enterprise's business practices (including knowledge management), workplace organization or external relations that has not been previously used by your enterprise.

- it must be the result of strategic decisions taken by management
- exclude mergers or acquisitions, even if for the first time

8.1. During the four years 2016-2020, did your enterprise introduce:

New business practices for organizing procedures (i.e., supply chain management, business re-engineering, knowledge management, lean production, quality management, etc.)	Yes	No
New methods of organizing work responsibilities and decision making (i.e., first use of a new system of employee responsibilities, teamwork, decentralization, integration or de-integration of departments, education/training systems, etc.)	Yes	No
New methods of organizing external relations with other firms or public institutions (i.e., first use of alliances, partnerships, outsourcing or subcontracting, etc.)	Yes	No

If no to all options, go to section 9
Otherwise, go to question 8.2

8.2. How important were each of the following objectives for your enterprise's organizational innovations introduced between 2016-2020 inclusive? If your enterprise introduced several organizational innovations, make an overall evaluation - High/Medium/ Low/ Not used

Reduce time to respond to customer or supplier needs	High	Medium	Low	Not used
Improve ability to develop new products or processes	High	Medium	Low	Not used
Improve quality of your goods or services	High	Medium	Low	Not used
Reduce costs per unit output	High	Medium	Low	Not used
Improve communication or information sharing within your enterprise or with other enterprises or institutions	High	Medium	Low	Not used

9. Marketing innovation

A marketing innovation is the implementation of an innovative marketing concept or strategy that differs significantly from your enterprise's existing marketing methods, and which has not been used before.

- it requires significant changes in product design or packaging, product placement, product promotion or pricing
- exclude seasonal, regular, and other routine changes in marketing methods

9.1. During the three years 2016-2020, did your enterprise introduce:

Significant changes to the aesthetic design or packaging of a good or service (exclude changes that alter the product's functional or user characteristics – these are product innovations)	Yes	No
New media or techniques for product promotion (i.e., the first time use of a new advertising media, a new brand image, introduction of loyalty cards, etc.)	Yes	No
New methods for product placement or sales channels (i.e., first time use of franchising or distribution licenses, direct selling, exclusive retailing, new concepts for product presentation, etc.)	Yes	No
New methods for product placement or sales channels (i.e., first time use of franchising or distribution licenses, direct selling, exclusive retailing, new concepts for product presentation, etc.)	Yes	No
New methods for product placement or sales channels (i.e., first time use of franchising or distribution licenses, direct selling, exclusive retailing, new concepts for product presentation, etc.)	Yes	No

If no to all options, go to section 10.
Otherwise, go to question 9.2

9.2. How important were each of the following objectives for your enterprise's marketing innovations introduced between 2016-2020 inclusive?
If your enterprise introduced several marketing innovations, make an overall evaluation - High/Medium/ Low/ Not used

Increase or maintain market share	High	Medium	Low	Not used
Introduce products to new customer groups	High	Medium	Low	Not used
Introduce products to new geographic markets	High	Medium	Low	Not used

10. Innovations with environmental benefits

An environmental innovation is a new or significantly improved product (good or service), process, organizational method or marketing method that creates environmental benefits compared to alternatives.

- the environmental benefits can be the primary objective of the innovation or the result of other innovation objectives
- the environmental benefits of an innovation can occur during the production of a good or service, or during the after sales use of a good or service by the end user.

10.1. During the three years 2016-2020, did your enterprise introduce a product (good or service), process, organizational or marketing innovation with any of the following environmental benefits?

Environmental benefits from the production of goods or services within your enterprise

Reduced material uses per unit of output	Yes	No
Reduced energy use per unit of output	Yes	No
Reduced CO2 'footprint' (total CO2 production) by your enterprise	Yes	No
Replaced materials with less polluting or hazardous substitutes	Yes	No
Reduced soil, water, noise, or air pollution	Yes	No
Recycled waste, water, or materials	Yes	No

Environmental benefits from the after sales use of a good or service by the end user

Reduced energy uses	Yes	No
Reduced air, water, soil, or noise pollution	Yes	No
Improved recycling of product after use	Yes	No

10.2. During 2016-19, did your enterprise introduce an environmental innovation in response to:

Existing environmental regulations or taxes on pollution	Yes	No
Environmental regulations or taxes that you expected to be introduced in the future	Yes	No
Availability of government grants, subsidies, or other financial incentives for environmental innovation	Yes	No
Current or expected market demand from your customers for environmental innovations	Yes	No
Voluntary codes or agreements for environmental good practice within your sector	Yes	No

10.3. Does your enterprise have procedures in place to regularly identify and reduce your enterprise's environmental impacts? (For example, preparing environmental audits, setting environmental performance goals, ISO 14001 certification, etc.).

Yes: implemented before 2016
Yes: Implemented or significantly improved after 2016
No

11. Basic economic information on your enterprise

11.1. What was your enterprise's total turnover for 2016-2020?
Turnover is defined as the market sales of goods and services (Include all taxes except VAT).

- 2016-17 ……..
- 2017-18 ……..
- 2018-19 ……..
- 2019-20……..

11.2. What was your enterprise's total number of employees in 2016-19?

- 2016-17 ……..
- 2017-18 ……..
- 2018-19 ……..
- 2019-20……..

Part of the questionnaire is adopted and modified from-The Community Innovation Survey 2008 (CIS2008)https://ec.europa.eu/eurostat/documents/203647/203701/CIS_Survey_form_2008.pdf/e06a4c11-7535-4003-8e00-143228e1b308. It was shared with 250 executive in various roles (General Manager, and Above level only) in the Indian Food Processing SMEs. Out of this complete information was received from only 88 SMEs. First and foremost, the objectives which Indian Food Processing SMEs have for performing innovation is analyzed with the help of data collected through the survey conducted {attached annexure 1}. Mentioned below in table 3.1 reflects the nine objectives of doing innovation and each SME was asked to rank these objectives on a scale of 0-3 (Rating used for the same: 0-Not relevant, 1-Low, 2-Medium, and 3-High) as per the

importance of these objectives experienced by the SMEs while innovating. Mean is obtained by taking the average of innovation objectives by Indian Food Processing SMEs.

Table 8. Objectives of innovation in Indian Food Processing SMEs.

Objectives of Innovation	**Mean of Indian Food Processing SMEs s (n=88)**
Upgrading goods or services- in terms of quality	1.568
Expanding goods or services- in terms of variety	1.568
Growing market share	1.648
Penetrating in new markets for goods or services	1.386
Minimizing labor costs per unit output	1.602
Enhancing elasticity for manufacturing goods or services	1.216
Displacement of obsolete products or processes	1.864
Escalating volume for manufacturing goods or services	1.500
To boost well-being, safety, and protection of customers	1.761

The above table 3.b.1 throws light on the outcome for the nine objectives of the Indian Food Processing SMEs actively performing innovation and the mean value written against each objective reflects their significance and substance that these objectives hold for the Indian Food Processing SMEs under this study. Altogether, 88 Indian Food Processing SMEs responded to the survey which are actively involved in innovation and treats to boost well-being, safety, and protection of customers as their main objective for performing innovation especially in the form of product innovation during COVID times followed by displacement of obsolete products or processes as their second main objective, which is followed by growing market share and minimizing labor costs per unit output were the third and the fourth most important innovation objectives. And the fifth most important objective position is grabbed by upgrading goods or services- in terms of quality and expanding goods or services- in terms of variety particularly after the downfall faced by the SMEs as the aftereffects of COVID 19 Pandemic [13,14].

Methods, results, and discussion

The survey conducted throws light on the activities related to innovation in Indian Food Processing SMEs. Survey classified the activities into- involvement in inside R&D, involvement in outside R&D, buying /taking license for outside knowledge, product innovation and process innovation. The results indicate that of the 88 innovative Indian Food Processing SMEs, 81.8% SMEs involved in inside R&D activities, while 39.8% involved in outside R&D and 30.7% SMEs bought/took license for outside knowledge. Out of these 88 SMEs, 69.3% SMEs did perform product innovation in the 4 years, while 58% did perform process innovation. In a nutshell, the outcome of the survey suggested that Indian Food Processing SMEs are initiative-taking in involving themselves in inside R&D in comparison to the outside R&D and buying or taking license for outside knowledge. Other than these activities, product innovation was performed more in comparison to process innovation by the Indian Food Processing SMEs [13,14].

Table 9. Activities related to Innovation.

Indian Food Processing SMEs	**Involvement in Inside R&D (%)**	**Involvement in outside R&D (%)**	**Buying /taking license for outside Knowledge (%)**	**Product Innovation (%)**	**Process Innovation (%)**
N=88	81.8%	39.8%	30.7%	69.3%	58%

Collaboration with outside parties

For understanding the collaboration done by Indian Food Processing SMEs with outside parties- following outside parties which were used by the SMEs as their source of information and knowledge were studied-sister concerns of the SMEs, components or machinery suppliers, customers, rivals in the same industry, private consultants, R&D labs, Higher education institutions or universities, government offices, Exhibitions, Trade Fairs, Conferences, Publications, Journals and Professional Association bodies.

Table 10 throws light on the involvement of Indian Food Processing SMEs with the above mentioned outside parties in India.

Table 10. Collaboration with outside parties.

Collaboration with outside parties	1. Sister concerns of SMEs	2. Suppliers of equipment, machinery	3. Customers	4. Rivals	5. Private Consultants	6. R & D Institutions	7. Higher education institutions or universities	8. Government offices	9. Exhibitions, Trade Fairs, Conferences	10. Publications, Journals	11. Professional Association bodies	No collaboration % of SMEs	Collaboration with 1-5 outside parties -% of SMES	Collaboration with 6-11outside parties -% of SMES
Indian Food Processing SMEs (n=88)	77.3%	77.3%	86.4%	62.5%	65.9%	68.2%	53.4%	62.5%	59.1%	13.6%	59.1%	0%	31%	69%

The collaboration with outside parties was calculated with a range from 0-11, with 0 when no outside parties were used for collaboration, in comparison those Indian Food Processing SMEs got the score of 11 which collaborated with all outside parties. Collaboration was then asked by the informants to be grouped as low or high, SMEs which collaborated with 1-5 outside parties had low collaboration, on the other hand SMEs engaged 6-11 outside parties were assumed to have high collaboration.
Table 4.2 clearly reflects the collaboration range that 0% SMEs (n=88) did not collaborate with outside parties, 31% collaborate with 1-5 outside parties while 69%collaborate with 6-11 outside parties. In case Indian Food Processing SMEs are collaborating, the main collaborators (n=88) are their suppliers of equipment & machinery, and clients with 77.3% and 86.4% respectively. In contrast, Publications & Journals or Higher education institutions or universities are the least preferred collaboration parties for innovation as per the Indian Food Processing SMEs under this study.

Extent of openness in the innovation process of Indian Food Processing SMEs.

To further throw light on the activities related to innovation and the collaborations taking place with outside parties Table 4.3 reflects the Indian Food Processing SMEs position on average product innovation output {which is average of the sum of turnover from new to market products & turnover of new to firm's products doing product innovation} and the average extent of openness {which is the average taken of the external interactions SMEs engage in which is calculated in table 4.2} in the innovation process. The analysis reflects that in the Indian Food Processing SMEs the average product innovation output of SMEs in India under this study is 15 (n=88) and the average extent of openness in the innovation process of these Indian Food Processing SMEs (n=88) when collaborating with outside parties for their process of innovation is 4 out of 7[*].

Table 11. Innovation output and openness.

Extent of Openness	Number of Firms	Average of Product Innovation Output	Extent of openness in the Innovation Process
Indian Food Processing SMEs	88	15	4 out of 7*

* As no SME in Indian food processing industry under this study went for collaboration with any foreign firm:1.

Other enterprises within your enterprise group, 2. Suppliers of equipment, materials, components, or software, 3. Clients or customers, 4. Competitors or other enterprises in your sector, 5. Consultants, commercial labs, or private R&D institutes, 6. Universities or other higher education institutions, 7. Government or public research institutes.

Indian Food Processing SMEs product innovation output and Open Innovation

Multiple regression analysis was used to find out how ably prediction can be done regarding the product innovation output of Indian Food Processing SMEs by evaluating the collaborations done and the expenditure done on innovations. As per Drechsler and Natter 2012 [15], variables that suggested openness in the process of innovation were divided into two parts - (i) dependent variable i.e., product innovation output and (ii) independent variables were expenditure done by internal R&D team, buying R&D information or knowledge from outside parties, taking license for outside R&D, and the scope or extent of openness in the innovation process. Also, the control variables of the survey were- Size of the firm (to be SME as per the new definition given by the government in June 2020) and industry (to be Indian Food Processing) [16].

Variables- Dependent and Independent

Dependent variable – Under this study, product innovation output is the dependent variable which is measured to check the innovation performance of Indian Food Processing SMEs. This variable can reflect the capacity of the SMEs to perform innovation. The product innovation output under this study is calculated by taking the average of the sum of incomes in the last five years (2015 to 2020 year) from new to market products and incomes in the last five years (2015 to 2020 year) for SMEs performing product innovation from new to firm products.

Independent variable – Under this study the following variables were included (i)expenditure done by internal R&D team, (ii) buying R&D information or knowledge from outside parties, (iii) taking license for outside R&D (iv) scope or extent of openness in the innovation process. And these variables are continuous in nature. The variable reflecting the scope or openness in the innovation process concerning the collaboration with outside parties was calculated with the help of Drechsler and Natter (2012) formula - adapted and modified:

$$SOi = SKCji + \sum_{j=1}^{7} DCTji + \sum_{j=1}^{7} FCTji \quad (1)$$

Where-Under this study extent or scope of openness is calculated in the following manner:

SOi= Scope/ extent of openness of SME i

SKCji= Significance of knowledge obtained from collaboration which includes buying or taking outside knowledge j, as perceived by SME i {calculated in table 4.2}

DCTji* =Domestic collaboration type j used by firm i

FCTji* =Foreign collaboration type j used by firm i

*{conversion in binary “0” for no collaboration and “7” for all parties’ involvement} Together for Domestic +Foreign =Range from 0 to 14. “0” means No adoption of Open Innovation and “14” means High degree of Open Innovation.

Control Variables=Firm size {“0” score less than 50 employees and “1” score if equals to or more than 50 employees}

j= sister concerns of the SMEs; components or machinery suppliers; customers; rivals in the same industry; private consultants; R&D labs; Higher education institutions or universities; government offices.

Involvement in outside collaboration was taken as a continuous variable under this study, whereby 0 was given when SMEs do not use buying or take license for using outside information and knowledge and 1 was given by the informants when used. And for calculating domestic collaborations with outside parties, 0 was given when no domestic collaboration was done and 1 was given by the informants when used for each outside party and this ranged between 0 - 7 and the SMEs got 7 when collaborating with all potential collaborating parties. Similarly, for foreign collaboration score ranged from 0 - 7, but under this study it was 0 for all SMEs. On the grounds of the above analysis, range of 0 - 14 was utilized to give scores for the scope/ extent of openness in the Indian Food Processing SMEs, whereby SMEs could get 0 for not adopting any activity reflecting open innovation, on the other hand SMEs with 14 score are assumed to highest scope/ extent of openness in their innovation process. Under the study, SMEs size and Food Processing Industry was used as the control variable. In the survey conducted the SME size was calculated keeping in mind the number of employees it had and was coded in binary form whereby 0 was used for SMEs having less than 50 employees and 1 was used for SMEs having more than or equals to 50 employees.

Statistical analysis and results

Multiple regression analysis was used to find out how ably prediction can be done regarding the product innovation output of Indian Food Processing SMEs by evaluating the collaborations done and the expenditure done on innovations. Under this study (i) dependent variable i.e., product innovation output and (ii) independent variables were expenditure done by internal R&D team, buying R&D information or knowledge from outside parties, taking license for outside R&D, and the scope or extent of openness in the innovation process. Also, the control variables of the survey were - Size of the firm (to be SME as per the new definition given by the government in June 2020) and industry (to be Food Processing). On scrutinizing the data collected through the survey it was found that out of all the respondents 89 SMEs in Indian Food Processing SMEs gave complete response required for regression analysis and therefore, regression was performed only on these SMEs. Below in table 5.1 below reflects the summary of the regression model and its result. The independent variables account for 59% of the product innovation output variance (R2 =0.059).

Table 12. Regression model analysis and result of Indian Food Processing SMEs [13,14].

Independent Variables	**Dependent Variable**		**Mean**	**Standard Deviation**
	Coefficient	**p-value**		
Extent of Openness	0.009	1.462	0.147	0. 056
In-house R&D expenditure	0. 055	0.858	0.748	0. 084
Purchase of External R&D	0.021	0.617	0.502	0.063
Acquisition of External	0.032	0.796	0.428	0.071
Firm Size	0.015	0.140	0.889	0.034

Out of the independent variables of this study, following variables found to have less impact on the product innovation output in Indian Food Processing SMEs- (i) expenditure done by internal R&D team, (ii) taking license for outside R&D, and (iii) the size of the SME in terms of its employees. In contrast to this, (i) buying R&D information or knowledge from outside parties and (ii) and the scope or extent of openness in the innovation process have observed to have a powerful impact on the product innovation output. No doubt, it can be concluded that the scope/ extent of openness in the innovation process of Indian Food Processing SMEs had crucial, constructive, and positive impact on the product innovation output. Further it proposes that SMEs with higher extent of openness in their innovation process tend to have high level of Product innovation output.

Impact

The research done is highlighting the innovation taking place in Indian Food Processing SMEs with a special focus on open Innovation taking place in these SMEs and the exchange of information or knowledge taking place between inside - out and outside - in parties for the purpose of innovation. In addition, puts special focus on describing how SMEs' product innovation output related with the effect of outside-in and inside-out exchange of knowledge and information. Further, it analyzes how expenditure on innovation and collaborating with outside parties can help in the predicting product innovation output of Indian Food Processing SMEs. The analysis was done with the help of Jamovi to find out regression between the dependent variable - "Product innovation

output" & independent variables- "Extent of openness", "Inhouse R& D expenditure", "Purchase of R&D from outside sources", "Acquiring knowledge from outside sources" and control variable - "Indian Food Processing SMEs". And towards the end, it contains the summary of the survey done, which suggested that Indian Food Processing SMEs are proactively involved themselves in inside R&D in comparison to the outside R&D and buying or taking license from outside sources. Other than these activities, one more pointer came as a takeaway from the study, product innovation is performed more in comparison to process innovation by the Indian Food Processing SMEs.

Thus, it is imperative that Indian policymakers propose and implement policies that provide support/assistance to Indian food processing SMEs owned by women through training and skill development to help them succeed in the face of the COVID - 19 pandemic. The proposed suggestions may be useful in future academic studies and will help businesses solve difficult decision-making problems, allowing them to move closer to the Sustainable Development Goals of Goal 9 (Industry, Innovation, and Infrastructure), Goal 1 (No Poverty), and Goal 12 (Ensure a Sustainable Consumption and Production Pattern), especially now that COVID-19 is having such a negative impact on the Indian economy. In practical terms, the study includes interpretations and discussions that will help policymakers and related associations formulate and develop policies and procedures to empower Indian food processing SMEs to initiate Open innovation in their businesses in an effective manner and increase their product output.

Conclusions

To encapsulate the analysis of the data collected through the survey of the Indian Food Processing SMEs gives the following findings:

- SMEs in Indian Food Processing sector treat following as their main objectives- To boost well-being, safety, and protection of customers, growing their market share and upgrading goods or services - in terms of quality
- In - house R&D is preferred by most of the SMEs in comparison to the outside R&D or buying or taking license for the outside information/ knowledge.
- the most usual form of innovation in the Indian Food Processing SMEs is the Product innovation.
- SMEs and large go for collaboration with 4 on a range of 7 outside parties for innovation. Customers followed by suppliers are the most frequently collaborated parties for innovation whereas Publications & Journals or Higher education institutions or universities are the least favored ones.
- SMEs with higher extent of openness in their innovation process tend to have high level of Product innovation output.

To summarize, the survey data collected and analyzed with regression model presents the sketch of the Indian Food Processing SMEs and their innovation and open innovation activities. In depth this study reports the scope/ extent of openness in the innovation process of the Indian Food Processing SMEs and further throws light, on its influence on the product innovation output. The inferences of the above stated findings are studied in chapter-7 of this study. The data so collected under this study, emphasize on innovation and open innovation taking place in Indian Food Processing SMEs.

Conflict of interest

There are no conflicts to declare.

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DEVELOPING AND RANKING THE STRATEGIES OF ZARAND POWER PLANT USING QUANTITATIVE STRATEGIC PLANNING MATRIX AND BEST-WORST METHOD

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Highlight
This research aims to develop the strategic plan for the Zarand power plant and rank the developed strategies.

Abstract
Developing the power plants in any country is considered an economic development strategy as it changes the country's market despite the competitive pressures. However, to grow the electricity market, policymakers need to evaluate the domestic Strengths, Weaknesses, Opportunities, and Threats (SWOT) of electric power plants. So, the necessity of a strategic plan for the power plants is inevitable to reach the goals such as eliminating the shortcomings, and meeting the desired criteria of an organization, such as more market share, acceptable profitability, customer satisfaction, increasing profit growth rate, and productivity through economic and cost-effective operations. Therefore, in this paper, the Zarand power plant in Iran is chosen as a case study to develop the associated strategies and rank them. A power plant strategic plan was generated by using a SWOT matrix. Then, the developed strategies were prioritized using a quantitative strategic planning matrix (QSPM) and the best-worst method (BWM). The results confirm that developing the main product (electricity power), managing water consumption, and providing equipment are the most critical strategies for the Zarand power plant. Findings also demonstrated that the results of the BWM method are more accurate and correct than the QSPM method for prioritizing strategies.

Keywords
power plant; strategic planning; multi-criteria decision-making; best-worst method.

Introduction
Today we see a lot of rapid changes in different environments- the changes which create challenges for organizations that are interdependent upon these environments and changes. These challenges make concerns for managers to achieve organizational goals to respond these changes. So, the researchers have used strategic planning as an influential tool for dealing with the challenges in management. Private and public enterprises use strategic management extensively to withstand the onslaught of market competition and environmental change. The complexity and delicacy of business decision-making make strategic management essential. The research

shows that 70 - 90% of the developed strategies failed in the implementation phase. Therefore, the implementation of strategy is more complicated than the development of good strategy [1]. The most significant problems that led to the development and popularization of the strategic management perspective in the historical planning were the environmental conditions and the resulting changes in the competitive market, and the need for aligning the operating systems with the chosen strategy to survive under such conditions [2]. Without a strategy as a management tool, there is no guideline for exploring new chances. So, the organization either passively waits for an opportunity or uses a shot in the dark technique [3].

Strategic planning gives the manager a clear picture of the organization and its goals and coordinates its activities. So, technological, social, and political changes, the complexity of the organization's external environment, the organization's extensive and numerous relationships with the environment and the longevity of the connections have made strategic planning necessary, and inevitable for the organization. In the rest of this section, the previous research, and studies in this field are briefly reviewed. In a study, to strategically plan marketing and select the appropriate strategy, Samadi and Fakher applied the Analytical Hierarchy Process (AHP) technique for Ahvaz Pipe Manufacturing Company in 2009 [4]. Another study was conducted by Amini et al. [5] to design and formulate the strategy of the North Drilling Company. Some tools such as the Internal and External Factor Evaluation (IFE and EFE) matrix, and the Strengths, Weaknesses, Opportunities, Threats (SWOT) matrix have been used in this [5]. In 2010, Hosseini and Shakhsian studied the factors affecting the strategy development of low-cost airlines using the SWOT matrix and Friedman test [6]. In another study, Salmani and Paleshi formulated the strategic planning of Sanat Choob Shomal Company to monitor and analyze the long-term goals of the company using strategic planning techniques such as internal factors (weaknesses and strengths) and external factors (threats and opportunities) and evaluate and propose appropriate strategies to achieve these goals [7]. Regarding EFE and IFE matrices in the input stage, they extracted the Internal External Matrix (IEM) [7].

Then, they identified different strategy options and prioritized them by the quantitative strategic planning matrix (QSPM) using the IEM and the SWOT matrices and information obtained from the statistical population of the matrix at the decision-making stage [7]. In 2016, Shahsavari and Moosavirad drew up a strategy map for the power installation company, one of the subsidiaries of the Mapna Group [8]. The combination of the SWOT, QSPM, and DEMATEL methods was used in their research [8]. In another study, Bagheri and Safaei formulated and prioritized human resource strategies in a telecommunications contractor company using the SWOT matrix and Balanced Score Card (BSC) [9]. In the field of transportation, using a combination of the SWOT and QSPM approach, the strategies to improve the position of the urban transportation system in the Shahrekord were developed and ranked [10]. In 2009, Wickramasinghe and Takano described a Sri Lankan tourism case study as a systematic approach and analytical tool for tourism revitalizing and strategic marketing planning, using a combination of the SWOT matrix and AHP [11]. In 2016, Shi assessed the competitive landscape for power integration at the Association of Southeast Asian Nations [12]. In their research, the strengths, weaknesses, opportunities, and threats developing green power were explored by using the SWOT analysis method. Kumar and Singh explored the impact of COVID-19 on the Agrifood Supply Chains (AFSC) and the possible strategies for improving the resilience of the AFSC [13]. They used the Best-Worst Method (BWM) for rating the importance of the identified strategies. In another research, the strategic plan of the beauty service industry in South Korea was developed using the SWOT method, and the AHP [14]. They found that the beauty service industry must deal with financial problems and employee stress [14]. Aliewi et al. also explored strategic management options for desalination using MCDM analysis in Kuwait [15]. They evaluated and tagged different management and policy options at the strategic level for the security and sustainability of water resources in the future for using all water users in Kuwait. The reuse wastewater for agricultural purposes was investigated in their research using MCDM techniques [15]. In 2017, Niu et al. explored the relationship between coal use and air pollution by proposing a practical Electric Power Substitution (EPS) mechanism. Finally, they explored EPS markets and policies. They used the SWOT method to investigate the strengths and weaknesses, opportunities, and threats of using EPS [16]. A study was conducted to prioritize the renewable power propellants in Iran using the Delphi- DEMATEL combined approach and network (fuzzy) analysis [17]. The "technological capability" and "political strength" propellants were considered the essential propellants to develop future scenarios about renewable power as well as strategic plan creation [17]. In another study at the Great Tehran Electrical Distribution Company, the operating strategies include power supply development, standardization of methods and processes, organizational development, and leadership style [18]. Finally, operational agility was extracted using the SWOT model. Then, the risks affecting the strength of electricity distribution and strengthening relationships with customers were identified using the ANP method in the same study [18]. Strategic factors in the Fars Province Power Distribution Company were ranked with the Fuzzy BWANP method by researchers [19]. Recently, research presented five suggestions to the organizations for their strategic planning [20]. The first suggestion was to consider their desired

characteristics in their vision and mission statements. The second suggestion was the application of Actionable, Quantitative, Comparative, and Divisional (AQCD) factors for analyzing SWOT. The third one was the usage of different sources for gathering the required information. The fourth one was the prioritization of the developed strategies by using QSPM. The final suggestion was to use software such as Excel in the strategic planning. Strategic thinking is no longer an option, but a necessity that guarantees the survival and success of an organization [21]. Due to the limitation of organizational resources, policymakers need to prioritize the implementation of their strategies [22]. Developing the country's power plants is undoubtedly considered a strategy for the country's economic growth. Also, it is a necessity because the domestic markets will be changed in the coming years, despite competitive pressures. Therefore, the need to develop a strategic plan for the Zarand power plant in Iran is fully felt to approach the goals that, while eliminating shortcomings, meet the desired criteria of an organization, such as more market share, acceptable profitability, customer satisfaction, increasing profit growth rate, and productivity through economic and cost-effective operations. According to previous articles and research, the BWM has not been used to rank the strategies. In the present study, the Zarand power plant strategic plan is generated. Then, the strategies of the power plant are prioritized using the QSPM and BWM.

This paper is structured as follows: The second section presents the research methodology for determining the best strategies using the QSPM and the BWM. Then, the results of this research are discussed in the third section. Finally, the conclusions and future suggestions are expressed in the fourth section.

Methods

To formulate the strategic planning of the Zarand power plant, first, the mission statement of the Zarand power plant was identified. According to Figure 1, the strengths, weaknesses, opportunities, and threats of the organization need to be identified and analyzed by IFE, and EFE at the input stage. Then, Internal External Matrix (IE) and Evaluation Matrix Strategic Position and Action (SPACE), and SWOT matrix need to be used by the strategic committee meetings for formulating the organizational strategies. SWOT analysis can help policymakers identify their primary strategy for achieving their goals. However, when the number of identified strategies is considerable, prioritizing the strategy cannot be done by the SWOT method. To deal with this issue, scholars usually use QSPM by weighting criteria [23–27]

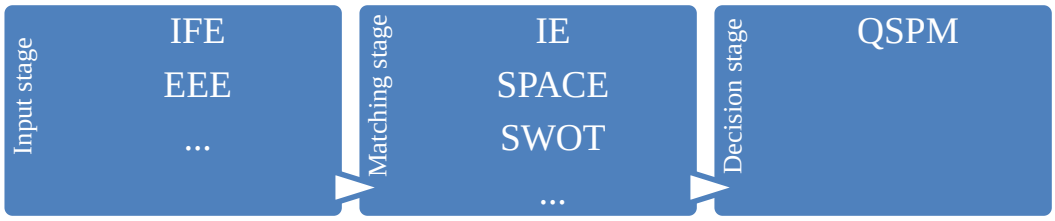

Figure 1. Comprehensive strategy formulation framework [22]

For prioritizing strategies, different pairwise comparison-based methods can be applied [28]. One group of the pairwise comparison-based methods uses a single vector, such as QSPM, Swing, and SMART family methods [28]. The other pairwise comparison-based method uses a full matrix in its algorithm (e.g., AGH) [28]. However, each of them has its strengths and weaknesses. Although the one vector methods are very data and time-efficient, the consistency of the provided pairwise comparisons cannot be evaluated [28]. In contrast, the whole matrix methods can check the consistency of the provided pairwise comparisons, while they are not data and time-efficient. In other words, asking too many questions from the decision-makers in whole matrix methods can create confusion and inconsistency among the decision-makers. BWM - introduced in 2015 for weighting the criteria- stands in the middle of these two groups [28]. BWM is the most data and time-efficient method that can check the consistency of the provided pairwise comparisons. BWM has some similarities with the AHP method [29]. For instance, both questionnaires have pairwise comparisons, and both are set with a nine degrees spectrum. However, the AHP technique calculates n× (n-1)/2 connections for the comparisons, but the BWM technique uses (n-2)×2 connections [29].

Thus, BWM, with fewer comparison data, has more consistent comparisons than AHP, which leads to reliable results. Therefore, in BWM, the respondent does not get bored. Therefore, according to managers' and experts' opinions in the power plant strategic committee, after prioritizing the strategies obtained using the QSPM and the BWM, the appropriate strategies for the Zarand power plant are proposed.

Determining the best strategies using QSPM

The most popular quantitative analysis method to prioritize the attractiveness of the proposed strategies is QSPM. In this method, it is possible to objectively identify various strategies among the best ones. The results and tables obtained in previous data entry and comparison stages are used to conclude the preparation strategies and to prepare and adjust the matrix [22].

The steps for preparing QSPM are presented as follows:

Step 1: The key opportunities and threats of the organization and its internal strengths and weaknesses obtained from the internal-external survey are written in the matrix. In this column, the primary factors that determine the success and failure of the organization are transferred directly from IFE and EFE to QSPM.

Step 2: Each opportunity, threat, strength, and weakness are weighted based on its importance. Therefore, the sum of opportunities and threats consequence equals one and the sum of strengths and weaknesses consequence equals one.

Step 3: The type of strategy is determined using the aforementioned methods in the methodology section. Then the strategy options related to the kind of strategy are presented.

Step 4: The attractiveness score of the strategy is achieved by each of the SWOT factors. In this step, the scores (1), (2), (3), and (4) are given to unattractive, somewhat attractive, sensible attractive, and very attractive, respectively.

Step 5: Calculate the sum of attractiveness scores.

Step 6: The total weighted scores are calculated, and the strategy with the highest weight scores is selected as the top strategy.

Determining the best strategies using BMW [29].

BWM includes the following steps:

Step 1: Determining a set of decision criteria.

Step 2: Determining the best (most desirable, most significant) and worst (most undesirable, least significant) criteria.

Step 3: Determining the importance of the best criterion compared to others, using a number between 1 and 9.

(1) $$AB = (a_{B1}, a_{B2}, \dots, a_{Bn})$$

Step 4: Determining other criteria's importance compared to the worst criteria, using a number between 1 and 9.

(2) $$AW = (a_{1w}, a_{2w}, \dots, a_{nw})$$

Step 5: Calculating the final weights of criteria $(W_1^*, W_2^*, \dots, W_n^*)$ by solving the following optimization problem.

(3)
$$Min\ \xi$$
$$\left|\frac{W_B}{W_j} - a_{Bj}\right| \leq \xi$$
$$\left|\frac{W_j}{W_w} - a_{jw}\right| \leq \xi$$
$$\sum_j W_j = 1$$
$$W_j \geq 0\ ,\forall\ j$$

Results and discussion

According to the information obtained from the strategic committee meetings of the power plant, six main strengths, weaknesses, opportunities, and threats of SWOT of the company were finalized in Table 1.

Table 1. SWOT of the Zarand power plant.

Strengths (S)
S1 - Optimization, modernization, and technology change of systems S2 - The efficiency of the power plant is increasing compared to the design efficiency. S3 - Specialized and skilled human resources S4 - Establishment of quality management systems (ISO9001, OHSAS 18001, ISO14001, HSE, ISO 10015, and Information Security Management (ISMS)) in the company S5 - The company has suitable and improving computer systems and necessary and sufficient training is given. S6 - Capability and experience in organizational management
Weaknesses (W)
W1 - The company is weak according to liquidity and has limited access to financial resources. W2 - System wearing W3 - High products cost due to low production capacity and machinery wearing W4 - A high rate of domestic consumption to the extent of production W5 - Leaving the service of experienced temporary contracts employees W6 - A low ratio of specialized in-service training
Opportunities (O)
O1 - Strategic products (electrical power) O2 - Electricity market monopoly O3 - Government support policies in the supply sector O4 - Government support policies in the development sector O5 - The need of urban industries for technical capabilities, services, and by-products of the company O6 - The power plant is important for maintaining the national electricity network strength in the country's southeast
Threats (T)
T1 - Lack of regional water resources T2 - Low quality of extracted raw water T3 - Economic sanctions on the supply of spare parts T4 - Rising fuel prices due to the removal of subsidies from Power carriers T5 - Laws of the Environment Organization to control environmental pollutants T6 - Geographical location of the Zarand city and seismicity of the region and its effect on power plant production performance.

The influence of various internal and external factors has been challenged during the consequent meetings. Ultimately, the list of internal and external factors has been finalized and evaluated by the strategic committee members. The results of internal and external factors are presented in Tables 2 and 3. In these two tables, as mentioned, in addition to a list of internal and external influential factors, there are also columns for scoring and the importance of the factors. Total scores in each score table will be 0 - 4 with an average of 2.5.

As seen in Table 2, S1 - optimization, modernization, and technology change of systems, and S6 - capability and experience in organization management are the main strengths of the organization that need to be considered. In addition, W2 - system wearing, and W1 - the company is weak according to liquidity and has limited access to financial resources identified as the main weaknesses of the company.

Table 3 shows that O1 - strategic products (electrical power), and O4 - government support policies in the development sector are the main opportunities that need to be considered by the company. Moreover, T1 - lack of regional water resources, and T2 - low quality of extracted raw water are the major threats that need to be considered by the company.

Table 2. IFE Matrix (Strengths and Weaknesses).

Priority internal factors	**Significance factor (0-1)**	**Rate (1-4)**	**Score (rank coefficient) (0-4)**
S1- Optimization, modernization, and technology change of systems	0.109	4	0.436
S2- The efficiency of the power plant is increasing compared to the design efficiency.	0.054	3	0.162
S3- Specialized and skilled human resources	0.081	3	0.243
S4- Establishment of quality management systems in the company	0.081	3	0.243
S5- The company has suitable and improving computer systems and necessary and sufficient training is given.	0.081	3	0.243
S6- Capability and experience in organization management	0.108	3	0.324
W1- The company is weak according to liquidity and has limited access to financial resources.	0.108	2	0.216
W2- System wearing	0.108	3	0.324
W3- High products cost due to low production capacity and machine wearing	0.081	2	0.162
W4- A high rate of domestic consumption to the extent of production	0.081	2	0.162
W5- Leaving the service of experienced temporary contracts employees	0.054	1	0.054
W6- A low rate of specialized in-service training total score	0.054	2	0.108
Total score	1		2.677

Table 3. EFE Matrix (Opportunities and Threats).

Prioritized external factors	**Significance factor (0-1)**	**Rate (1-4)**	**Score (rank coefficient) (0-4)**
O1- Strategic products (electrical Power)	0.122	4	0.488
O2- Electricity market monopoly	0.097	3	0.291
O3- Government support policies in the supply sector	0.097	3	0.291
O4- Government support policies in the development sector	0.122	4	0.488
O5- The need of urban industries for technical capabilities, services, and by-products of the company	0.049	2	0.098
O6- The power plant is important for maintaining national electricity network strength in the southeast of the country	0.073	2	0.146
T1- Lack of regional water resources	0.122	3	0.366
T2- Low quality of extracted raw water	0.098	3	0.294
T3- Economic sanctions on the providing the spare parts	0.073	3	0.219
T4- Rising fuel prices due to the removal of subsidies from Power carriers	0.049	1	0.049
T5- Laws of the Environment Organization to control environmental pollutants	0.049	2	0.098
T6- Geographical location of the Zarand city and seismicity of the region and its effect on power plant production performance	0.049	2	0.098
Total score	2.926		1

Based on the internal-external evaluation matrix of the Zarand power plant and the scores of the evaluation matrices of internal factors and external factors, the strategic position of this organization is depicted in Table 4. According to Table 4, strategies for maintaining existing markets -with a focus on advertising and marketing to replace probably lost market share - and continuing to produce current products- with a focus on increasing the productivity and maintenance of facilities commonly used in this area. Consequently, the company's primary strategy is to develop the main product and expand its product availability and production in the Iranian electricity market.

Table 4. Internal- external factors evaluation matrix (IE)

			The final score of the IFE		
			weak	medium	strong
			1 - 1.99	2 - 2.99	3 - 4
The final score of the EFE	Strong	3 - 4	1	2	3
	Medium	2 - 2.99	4	5	6
	Weak	1 - 1.99	7	8	9

The factors affecting the company's activities were analyzed to determine appropriate strategies for the Zarand Power Generation Management Company. Ten main strategies were identified by taking the opinion of relevant experts and members of the strategic committee. Table 5 represents the proposed strategies such as main product development (electrical power), supply management of parts and equipment, water consumption management, fuel consumption management, power consumption management, and managing company expenses and income.

Table 5. Strategies of the Zarand Power Generation Management Company.

Strategy 1	Main product development (electrical power)
Strategy 2	Supply management of parts and equipment
Strategy 3	Water consumption management
Strategy 4	Fuel consumption management
Strategy 5	Power consumption management
Strategy 6	Managing company expenses and income
Strategy 7	Expansion of services and ancillary products
Strategy 8	Continue to implement and update quality management systems
Strategy 9	Attract and hire specialized and efficient human resource
Strategy 10	Holding specialized training

The strategic position of the company was also investigated by the SPACE chart. Table 6 shows that return on investment, liquidity power, and working capital are the main financial strengths of the company. Ease of entering the market and inflation are also identified as the major industrial and environmental strengths of the company, respectively. Finally, controlling the suppliers of raw materials and distributors of manufactured goods is presented as the most competitive advantage of the company. Based on the scores obtained from Table 6, Figure 2 shows that the company's position in the SPACE chart is conservative. In such a condition,

the organization must maintain its proper competencies and avoid exposing itself to risks. The most conservative strategies include market penetration and development, product development, and diversification.

Table 6. The internal and external strategic position of the Zarand power plant.

Variables related to Financial Strengths (FS)	**Score**
Return on investment	4
Liquidity power	4
Working capital	4
Acquisition of fixed assets	3
Ease of exit from the market	1
Risk of trade	1
Grade point average	2.83
Variables related to Industrial Strengths (IS)	**Score**
Growth potential	3
Profitability	1
Financial strength	2
Necessary skills in technology	3
Use of resources	3
Ease of entering the market	5
Efficiency	3
Optimal use of capacity	4
Grade point average	3
Variables related to environmental strength (ES)	**Score**
Technological changes	-2
Inflation	-4
Change in demand	-1
Products prices of competing companies	-3
Barriers to market entry	-1
Competitive pressure	-3
Demand elasticity in terms of price	-2
Grade point average	-2.28
Variables related to Competitive Advantage (CA)	**Score**
Market share	-5
Products quality	-1
Life cycle	-1
Customer loyalty	-1
Ability to exploit competition	-5
Technical knowledge	-3
Controlling over the suppliers of raw materials and distributors of manufactured goods	-6
Average	-3.14

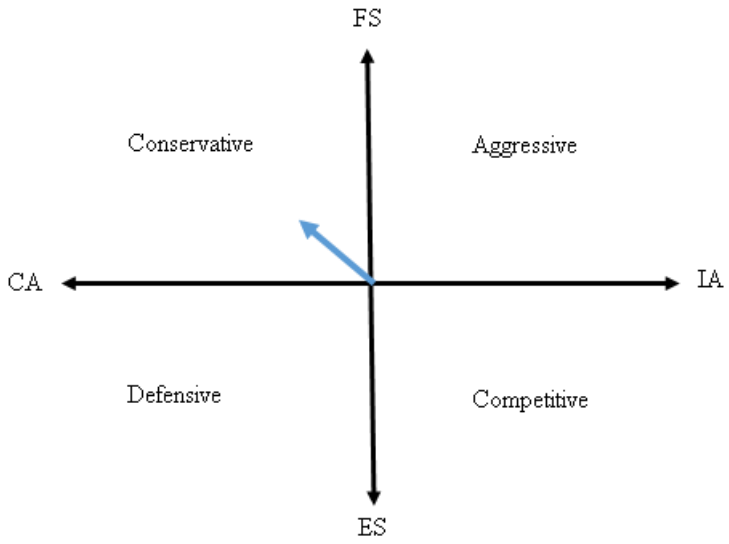

Figure 2. Company position on SPACE chart.

Prioritizing the developed strategies using QSPM

In QSPM, the quantitative factors and their significant weight are the same as the items' weights mentioned in the IFE and EFE. Attractiveness scores have been obtained by comparing strategies and internal and external important factors based on the opinion of the company's strategic committee members and the fitness of each strategy with each element, along with a logical reason.

The sum of attractiveness scores of determined strategies according to QSPM is a suitable criterion to choose among strategies. Accordingly, the prioritization for the proposed strategies is given in Table 7. Table 7 depicts that, based on the QSPM results, (1) main product development (electrical power), (2) management company expenses and income, (3) supply management of parts and equipment, (4) power consumption management, and (5) water consumption management are the top five strategies of the company.

Table 7. Prioritization of strategies with QSPM.

Strategy priority	**Strategy description**	**Strategy score**
1	Main product development (electrical power)	6.061
2	Management company expenses and income	5.9
3	Supply management of parts and equipment	5.324
4	Power consumption management	5.314
5	Water consumption management	5.063
6	Fuel consumption management	4.976
7	Attract and hire specialized and efficient human resource	4.368
8	Continuation of implementation and updating of quality management systems	4.315
9	Development of services and ancillary products	4.161
10	Holding specialized training	3.639

Prioritizing the developed strategies using BWM

After using the QSPM method for prioritizing the identified strategies, the priority of strategies was also investigated using BWM. Based on the BWM, Table 8 presents that (1) main product development (electrical power), (2) water consumption management, (3) supply management of parts and equipment, (4) managing company expenses and income, (5) power consumption management are the main five strategies that the company need to implement.

Table 8. Prioritization of the strategies based on the BWM.

Strategy priority	Strategy description	Strategy score
1	Main product development (electrical power)	0.269
2	Water consumption management	0.238
3	Supply management of parts and equipment	0.124
4	Managing company expenses and income	0.099
5	Power consumption management	0.075
6	Attract and hire specialized and efficient human resource	0.063
7	Fuel consumption management	0.056
8	Holding specialized training	0.030
9	Continue to implement and update quality management systems	0.028
10	Development of services and ancillary products	0.024

According to the results of both methods presented in Table 9, the main product development strategy was chosen as the most significant strategy in the Zarand Power Generation Management Company. Moreover, according to Table 9, the top five strategies of the company are similar in these two methods. However, only some of these strategies have different ranks in these two prioritizing methods. In addition, the conservative strategy that was found in this research for the company is similar to the network planning and maintaining strategy that was found for Tehran Electrify Distribution Company in Iran [18]. The importance of company expenses management and power consumption management strategies in current research are also similar to the findings of [19] for Fars Electricity Distribution Company.

Table 9. Comparison of prioritization through QSPM matrix and BWM method.

Strategy rating	Prioritization based on the QSPM matrix	Prioritization based on the BWM method
1	Main product development (electrical power)	Main product development (electrical power)
2	The company expenses and income management	Water consumption management
3	Providing equipment management	Providing equipment management
4	Power consumption management	The company expenses and income management
5	Water consumption management	Power consumption management
6	Fuel consumption management	Attraction and employment of specialized and efficient human resource
7	Attraction and employment of specialized and efficient human resource	Fuel consumption management
8	Continue to implement and update quality management systems	Holding applied specialized training
9	Developing the services and ancillary products	Continue to implement and update quality management systems
10	Holding special applied training	Development of services and ancillary products.

Impact

Secondly, due to the lack of regional water resources, and the low quality of extracted raw water, the power plant's managers need to manage the water consumption in the power plant. Thirdly, since Iran faced the economic sanctions on providing the spare parts, this power plant needs to have a robust plan for supplying its spare parts and equipment. Regarding the strategy of managing the company's expenses and income, the power plant needs to provide a road map for reducing its production cost associated with its human resources and maintenance, as well as an operational plan for increasing its income from the customers by reducing its equipment's shutdowns. Based on the power consumption management strategy, the power plant should balance the power consumption of customers during the pick and off-pick periods by different incentive plans.

According to the case study of the power plant, this study has regional impacts. By implementing a suitable strategy, a sustainable environment can be achieved in the future for this power plant. Ten strategies have been identified in this paper. Some strategies have environmental impacts, such as water consumption management and fuel consumption management strategies. Some identified strategies also have social effects, such as attracting and hiring specialized and efficient human resources, power consumption management, and holding specialized training strategies. Finally, the economic impacts of the proposed strategies can be seen in strategies such as managing the company's expenses and income and supply management of parts and equipment.

Due to the novelty of the decision-making method used in the present study, the proposed approach can help policymakers prioritize the strategies effectively in other case studies. In other words, the BWM applied in this study improved the strategy formulation framework 22 by efficiently reducing the vagueness of the whole decision-making process.

Conclusions

In this research, the primary strategy of the investigated power plant was identified in the area that the company needs to develop the main product and expand its product availability and production in the Iranian electricity market. Regarding to the reviewed articles, the novelties of current research are the application of the BWM method for ranking the power plants' strategies, as well as the combinational use of SWOT and QSPM, and BWM. As seen in the results section, the suggested ten strategies for the investigated power plant were prioritized by QSPM and BWM methods. The main product development strategy was chosen as the most significant strategy in this power plant. Moreover, the top five strategies of the company are similar in these two methods. However, only some of these strategies have different ranks in these two prioritizing methods. The results depicted that the best five selective strategies include main product development (electrical power), water consumption management, supply management of parts and equipment, managing company expenses and income, and power consumption management. Therefore, the company's managers must invest in the plan and implementation of the main suggested strategies.

In terms of time, this kind of strategic management requires a long time. Thus, the power plant must spend a lot of time on planning and implementing the prioritized strategies, as well as evaluating the impacts of these strategies on the power plant's performance. Therefore, it is recommended to investigate the effectiveness of the proposed strategies on the company's performance in the future. The results of this research can be applied in similar power plants with similar social, political, economic, and environmental conditions. Moreover, according to the dynamic and modification of companies' internal-external factors, the strategies need to be revised regularly by the presented approach for further study.

Due to the novelty of the BWM used in the present study, it is suggested that the proposed approach be used to prioritize strategy plans in other organizations and industries. Moreover, using fuzzy logic of the AHP method or a multi-objective genetic algorithm to select the proposed strategies, with the ability to calculate the outcome of a group of strategies and compare the simultaneous effect of several parameters to meet company goals, is a suitable tool in strategic planning. For future research, scholars can consider different economic, environmental, and social criteria associated with the strategies, such as the marginal profit, carbon footprint, water footprint, implementation period, and social adoption. Moreover, if there are different economic, environmental, and social criteria for ranking the strategies, other multi-criteria decision-making methods such as TOPSIS, VIKOR, ELECTRE, and PROMETHEE can be applied. Therefore, for further study, it is recommended to use other multi-criteria decision-making methods for prioritizing companies' strategies and compare the results with the findings of this research.

Conflict of interest

There are no conflicts to declare.

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STATUS OF FARMERS' GARLIC MARKET CHANNEL CHOICES IN RESPONSE TO GARLIC VALUE CHAIN IN LIBOKEMKEM DISTRICT, SOUTH GONDAR ZONE, ETHIOPIA

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Abstract
This research was conducted to identify the key market outlets and their determinants. Primary data was collected from 400 garlic producers, 37 traders, and 12 consumers. Collectors, wholesalers, retailers, and consumers' marketing channels were identified. Of these, wholesalers were the preferred market channel by 93.75% of garlic producers. The results from a multivariate probit model showed that lagged price, experience, quantity produced, land allotted, education, sex, oxen, and market information influence garlic producers' market outlet choice decisions. The study suggested that garlic producers need to be supported to select the right market-place for maximizing their farm profit.

Keywords
district; garlic; households; marketing channels; multivariate probit model.

Introduction

Ethiopia is known for producing various vegetable crops in different agroecological areas. Vegetables are indispensable horticultural crops, from their roles in people's health to overcoming economic setbacks in food insecurity and poverty reduction. Create new market prospects that, in turn, can provide income and employment opportunities in different functions of its value chain [1,2].

As a result of its excellent market value, the production and commercialization of vegetal produce with rotation in pulses is increasing. Allium Sativum L (Garlic), along with onion, is a unique commercially significant vegetal produce grown aimed at family use, sale, nourishment treating, and enhancement in the form of oil, minerals, or powder [3]. As China (66%) led garlic production, followed by South Korea and India (5% each), Ethiopia ranked 12th, 17th, and 10th in terms of production, productivity, and area coverage correspondingly [4]. Ethiopia has great potential in garlic production and marketing. Ethiopia's low-land and mid-highland parts are particularly suitable for garlic production. Amhara Region ranks first, followed by Oromia and South Nations and Nationalities and peoples Region of Ethiopia in garlic production reported in 2018's Ethiopian central statistical agency [3]. The South Gondar Zone is endowed with vegetable production, of which onions and garlic are the main crops in this zone. In the 2021 production year, 280,216.8 tons of garlic were produced in rain feed and irrigation systems. In the same production year, 31,135.2 tons of garlic were produced in the current study area.

Irrigation system-based garlic productions seek improvement in size compared to an onion. However, the crop can be grown in rain-fed and irrigation systems using water pumps and river diversions. The product is supplied to the market right in the field, nearby, distant markets [5].

Garlic feels a unique flavour, and its processed items are used in sauces, soups, and seasoning foods through

grinding, cutting, or crushing. In the south Gondar Zone of the Amhara Region, Libokemkem, Dera, and Fogera are potential producers of vegetable crops. At the same time, garlic is cultivated in Libokemkem, which lets us focus on its value chain and market channel choice here. As it is a crucial cash crop in the district, it is grown from June to July and collected in October, and soon the area will be covered in chickpea. In addition, irrigated garlic is planted in November once cereals such as *tef* and maize are grown from May to October are harvested [6].

Market chains are essential components in the transformation of traditional hand-to-mouth agriculture to market-oriented agriculture. Markets play a vital role in bringing welfare for each market actor by choosing the one with a relative advantage [7]. The exploitation of this opportunity by farmers requires access to the product markets. In contrast, these markets may have a variety of integrations in passing garlic over some value additions [7,8].

Market chains of garlic consider production, distribution, processing activities, and marketing while the farmers sell their produce to local traders and agents. Even though they have the potential for high garlic production, farmers have limitations in identifying and supplying their products to the appropriate outlet. Farmers are restricted in farm gate markets as factors like market information, market access, distance to the market, bargaining power, lack of infrastructure, and appropriate handling [1,8]. There is a lack of market-led technologies at the farm gate as production is fragmented, and quality is not due. Besides, cleaning, sorting, grading, and storage facilities are negligible. Despite the increased input costs, other active value chain actors, such as brokers, transporters, processors, and traders, not farmers, have benefits [9]. Market outlet choice is not a simple duty. Its general notion is the decision to supply one product in various market channels with high margins [10]. It takes farmers' winning strategies set up, assessing the options of the garlic market among alternatives, and selecting the central market channel that increases the bargaining power of farmers to meet their expected benefit [11].

Accordingly, there are some related studies on market outlet choice [12]; on dairy farmers' markets [7,11]; on the wheat market [8,13]; pineapple farmers [10] and haricot bean market [1]. The market impact on channel choices on smallholder vegetal producers' revenue and production in the Tana Lake basin was also investigated. Simultaneously [14], had similar works in the Fogera district on onion market outlet choice determinants. However, these studies focused on identifying factors affecting specific product-market outlets though none of them tried to look at the garlic market. Like cereals, there is wide-ranging vegetable production in the South Gondar Zone. According to the report of the zone agriculture office, garlic is one of the important vegetable crops produced widely. However, there is no infrastructure, information, marketing, processing, price stability, and postharvest facility. Particularly in Libokemkem, which is the best in production potential in the zone, besides the above limitations, there is a high loss of returns when it is possible to achieve the maximum one since they do not even assess the profitable market outlet. It is believed to have happened because there is no well-documented information and continuous awareness creation for farmers in the area. Other chain actors, especially brokers, overact in the garlic market chain. Small-scale producers must choose great-value markets, for example, distributing and processing [13]. Thus, this study aims to assess factors affecting specific market outlets and the outlet(s) that generate the best margin for producers as the product passes the number of stages through processing and value additions in the market chain. This study can bring a significant role in improving farmers' income, welfare, and the general agricultural transformation; it shows clear directions of which market to participate in; whom actor to integrate; which market outlet to choose, and what postharvest technology to be applied for the long life of the produce.

The importance of conducting this research: The analysis of garlic product marketing channel decisions is just as significant as garlic producers' decisions about product features and prices. Traders and other farmers promote and sell a garlic product as it moves through its channel to its final user, depending on accurate channel selection. Choosing the proper marketing channel is crucial since it can determine whether a producer's product succeeds or fails. The kind of consumer to whom a garlic producer sells will affect the distribution channel they choose, and it should be their primary concern. It is also essential to consider the critical marketing channel functions while looking at the garlic market channel, which include Gathering and distributing information, setting up contacts and matching products to buyer's needs, negotiating prices, and paying the costs of channel activities, and physical delivery of products through the chosen channel are all part of the marketing channel selection process.

Method of research

The Study Area Description: The research was conducted in the Libo Kemkem District of the Amhara Region's South Gondar Zone. This district is in the middle of $12^0$39'66" and $12^0$42'45" N latitudes and $37^0$26'99" and 37^0 28'42" E longitudes. The district is surrounded in the West by Lake Tana, in the East by the East Ebenat, in the south by the Reb, which separates it from Fogera, and in the North by the North Gondar Zone.

The district is located 645 kilometres away from Addis Abeba and 70 kilometres away from the Reginal city of Bahar Dar, as shown in Figure 1. The district has a total area of 1,292.72km^2 and comprises 33 rural and two urban Kebeles. Of the total population found in the district (225,499), 149,709 garlic producers with two types of garlic production practices, namely rain and irrigation systems.

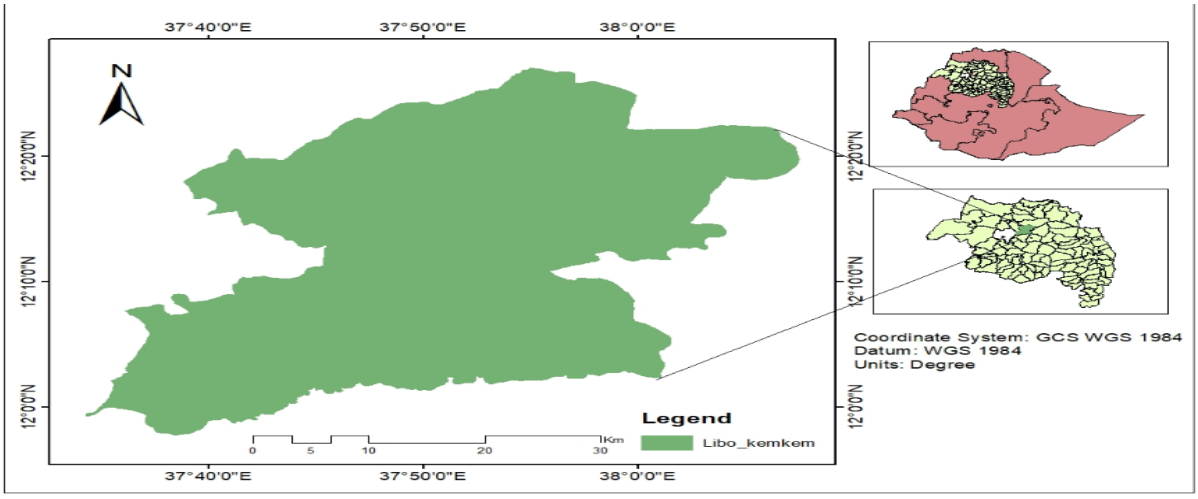

Figure 1. Location Maps of Libo Kemkem District. *Source: Arc GIS result, 2021.*

The district's elevation ranges between 1025-2960 meters above sea level. A rough topography includes elevations, heaving plains, and basins describing the study District. Only 42.12 % of the total area in the district is plain, with a slope ranging from 0 to 15 %. The remaining 33.23%, 17.7%, and 6.95% of this district's area were described to have a gradient of 15-30%, 30-50%, and more than 50%, respectively. Due to altitudinal variations, there are three agro-climatic Zones in Libo kemkem District: Dega, Weynadega, and Kolla. The area coverage of the agro-climatic zone of the district is Dega (18%), Weyna Dega (43%), and Kolla (39%). The annual rainfall ranges between 980-1700mm, with a regular of 1100mm and a mono modal trend from July to September. The maximum annual average temperature is 35 ° C and 16 ° C, respectively [15].

Garlic Production Trend: The District was selected purposively; because it is the potential area for garlic production, as shown in Figure 2.

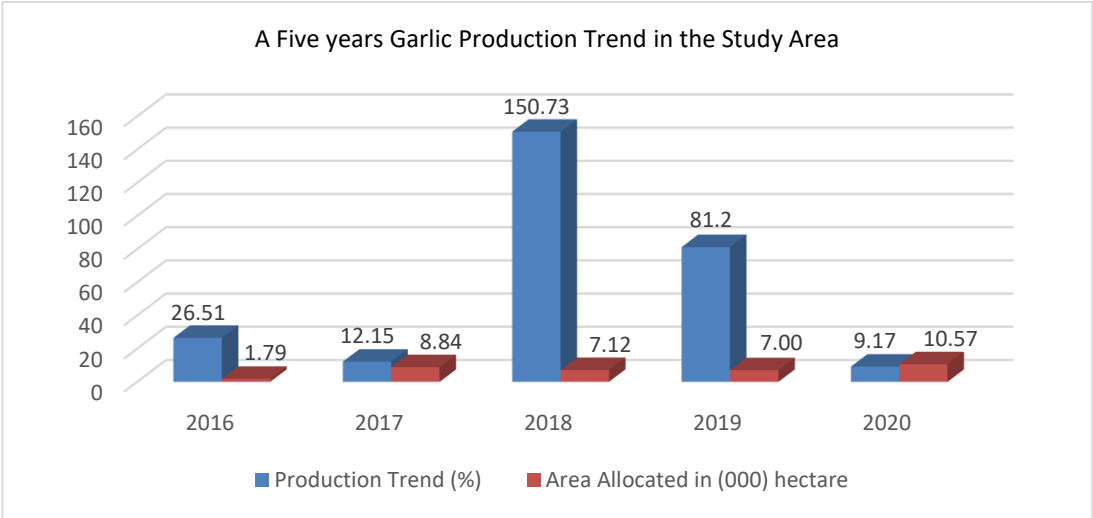

Figure 2. Garlic Production Trends in the Study Area. *Source: LDACOYYR, 2021.*

*Note: LDAOYR=Libokemkem District Agricultural Crop Office Year to Year Report.

Sample Size Determination and Sampling Procedures

To gather the primary data, a third-step random sampling procedure was used. Libo kemkem District was selected in the first stage based on its high garlic production potential. In the 2nd stage, five garlic-producing

kebeles were selected with simple random sampling. The sample households were chosen randomly from the sample kebeles' household list in the third stage based on the likelihood proportionate to the size of each kebeles' population. The total sample size was calculated using the [16] sample size determination procedure, which took into account a 95% confidence level, a 5% amount of variation, and a 6% precision degree to arrive at the appropriate sample size. The formula used to calculate and determine the sample size is:

(1) $$n = \frac{N}{1 + N(e)^2}, n = \frac{52{,}654}{1 + 52{,}654(0.05)^2} = 398\ but\ we\ took\ 400$$

Where: n designates sample size; N designates population size of the garlic producer Kebeles and e designates the degree of precision considered. The sample size for consumers, retailers, wholesalers, and collectors was also calculated for this study based on the number of traders established in the district, as indicated in Table 1.

Table 1. Sample Distribution of traders and consumers of garlic in the study area.
Source: Own computation Survey, 2021

Traders	**Adiszemen**	**Yifag**	**Woreta**	**Total**
Collectors	4	1	1	6
Wholesalers	22	1	3	26
Retailers	3	1	1	5
Consumers	7	2	3	12
Total	30	7	12	49

Data Type, Sources, and Collection Method

Primary data are gathered from starting producers and traders at various stages through a household questionnaire survey using structured questionnaires with both open-ended and closed-ended questions, concentrated on determinants influencing the market outlet choice. The questionnaires were pre-confirmed by rough producers in respective kebele during the preliminary survey, and after feedback, it was modified. Enumerators were trained on data collection, interviewing techniques, and how to approach respondents. A focus group discussion was made with the key actors using checklists. There were also individual annotations and collection meetings through chosen producers and agents. Secondary sources were used to gather secondary data.

Data Analysis

Descriptive statistics and econometric models were employed for data analysis.

Econometric Model

A variety of binary outcome/multivariate outcome models are applied to study two or more dependent variables and independent factors. The most popular models are mentioned below. Multinomial logit, Multinomial probit, and multivariate probit.

The multinomial logit model was used by several researchers [17–20]. However, the multinomial logit model employed for an outcome is nominal when the categories are supposed to be unordered. It is the most used nominal regression model. The main challenge in using this model comprises many factors, and it is easy to be overwhelmed by the complication of the results. The multinomial logit model assumes that data are case-specific; each independent variable has a single value for each case. It is also supposed that the dependent variable cannot be dreamily anticipated from the independent variables for any case.

The multinomial probit model uses discrete dependent variables that take on more than two outcomes that do not have a natural ordering. For this model version, the stochastic error terms are assumed to have independent, standard normal distributions. Researchers must have one observation for each decision-maker in the sample to employ the multinomial Probit model. As a result, most researchers did not use this model frequently. Numerous studies use the multivariate probit model to determine the factors influencing the market outlet choice of the given commodity. It was agreed that in the current research areas, sampled garlic farmers

have more than two market outlet options. The multivariate probit model is a generalization of the probit model, which is used to estimate many correlated binary outcomes jointly. It has more than two choices or allows simultaneous choosing multiple responses; it provides cross-effects and coincidences [21]. The researchers used the MVP (multivariate probit) model to estimate the choice factors of the garlic market outlet. The multivariate probit model was appropriate and used in the data of the current investigation to solve the drawbacks of the other models discussed above. The data was examined and found to be normally distributed. As a result, a multivariate probit model was used to investigate the factors influencing the choice of garlic marketing outlet in the research area. The choice of one type of market outlet depended on the choice of the other since smallholder farmers' decisions are interdependent, implying the need to estimate them simultaneously [22].
For household variation in market outlet choice and to estimate numerous correlated binary outcomes simultaneously, the multivariate probit model (mvprobit) was used. The multivariate probit method simulates the effect of a collection of independent variables on market outlet selection while also considering associations among unobserved disturbances and the linkages between market outlet choices. The observed result of market outlet selection can be modelled using a random utility formulation. Ponder the small holding producer (i=1, 2, ..., N), which must decide whether to use accessible outlets of the market. Let U_0 signify the profits to the producers who select wholesalers, and let U_k signify the advantage of the producer to choose the K^{th} outlet of the market: where K signifies the option of collectors (Y_1), wholesalers (Y_2), retailers (Y_3), and consumers (Y_4) and Y_n. The producer selects the K^{th} outlet of the market

(2) $$Y_{ik}^{*} = U_{ik}^{*} - U_o > 0$$

The take-home advantage (Y^{*}_{ik}) that the producer comes from selecting a market outlet is a concealed variable determined by the perceived independent variable (Xi) and the error term (ε_i):

(3) $$Y_{ik}^{*} = Xi\beta_k + \varepsilon_i, k = (Y1, Y2, Y3, Y4, \dots, Y_n)$$

The unobserved preferences in equation (2) are translated into the detected binary outcome equation for each option with the indicator function as follows:

(4) $$Y_{ik} = \{1 \; if \; Y_{ik}^{*} > 0 \quad and \; Y_{ik} = \{0 \;\; if \; Y_{ik}^{*} \;\leq\; 0 \;\; (K = Y1, Y2, Y3, Y4, \dots, Yn)$$

The multivariate approach allows for the selection of multiple market outlets; the error terms follow an MVD (multivariate normal distribution) together having a conditional mean of zero and a variance of one (for empathy of the parameters) where (μ_{y1} μ_{y2} μ_{y3} μ_{y4}) MVN ~ (0, Ω) as well as the symmetric covariance matrix is specified by:

(5) $$\begin{matrix} 1 & \rho y_1 y_2 & \rho y_1 y_3 & \rho y_1 y_4 & \rho y_1 y_n \\ \rho y_2 y_1 & 1 & \rho y_2 y_3 & \rho y_2 y_4 & \rho y_2 y_n \\ \rho y_3 y_1 & \rho y_3 y_2 & 1 & \rho y_3 y_4 & \rho y_3 y_n \\ \rho y_4 y_1 & \rho y_4 y_2 & \rho y_4 y_3 & 1 & \rho y_4 y_n \end{matrix}$$

Off-diagonal components in the covariance matrix are interesting because they illustrate the unobserved association among the stochastic components of the various kinds of outlets. Because of this assumption, equation (4) provides an MVP (multivariate probit) model that depicts the decision to choose a specific market outlet. This specification allows for correlation between error terms of numerous latent equations, stating unobserved characters that influence the choice of alternate outlets. After that, the log-likelihood function connection for a sample outcome is specified by:

(6) $$lnL = \sum_{i=1}^{N} \omega i ln\Phi(\mu i, \Omega)$$

Where is an optional weight for observation I, and Φ_i is the multivariate standard normal distribution with arguments and Ω, where μ_i can be denoted as:

(7) $$\mu i = (k_{i1}\ \beta 1 X_{i1}, K_{i2}\beta_2 X_{i2}, K_{i3}\beta_3 X_{i3}), while\ \Omega_{ik} = 1\ for\ j = K$$

(8) $$\Omega_{jk} = \Omega_{kj} = K_{ij}K_{ik}\rho_{jk}\ for\ j \neq K, K = 1, 2, 3 \dots \dots \dots with\ K_{ik} = 2yi_k - 1$$

Results and discussion

Statistical Descriptive Result of the Collected Data

The respondents' average age was 46.44, and they had been producing garlic for 23.48 years. The mean land allocation was 0.9 hectare, of which 0.34 hectare was irrigable land. The average annual garlic produced by sample farmers with a standard deviation of 3.54 was 11.27 quintals ranging from 4 to 20 quintals. Sample households located 9.45 kilometres away from the district market Table 2.

Table 2. The demographic and socioeconomic characteristics of the sampled households (continuous variables).
Source: Own Analysis 2021

Variables	**Mean**	**Minimum**	**Maximum**	**S.D**
Households' average age (in year)	46.44	24	80	11.97
Experience of the household head (in year)	23.48	2	52	11.47
Total land size holding of the household (in hectare)	5.9875	2	12	1.55
Total land allocation for garlic production (in hectare)	3.5765	1	6	1.32
Total irrigable land owned by households (in hectare)	1.34905	0.5	4	0.68
Number of total garlic produced (in quintal)	11.27075	4	20	3.54
Distance to the district market (in kilometre)	9.4475	2	18	3.76
Distance to the development centre (in kilometre)	4.56375	1	15	2.07

SD = standard deviation

From the result, the researcher confirmed that garlic production shows a positive status, which is a driving factor in the development of the garlic market. Garlic producers have extensive garlic production and marketing experience. It makes them sophisticated and decisive for the proper market selection. From the total sample, 96% of the respondents were male-headed, and 96% had access to market evidence. Their primary sources were family, friends, different traders, and through self-visiting and using mobile phones (65.25% of the respondents had their mobile phones) and other sources of information. With 1% and 5% significant levels, there was a significant mean difference between each kebele regarding non/off-farm income, access to market information, and mobile phones. Of the total respondents, 89% have access to credit, which has significant value in each kebele Table 3.

Table 3. Demographic and socioeconomic characteristics of the sampled households (dummy variables).
Source: Own Analysis 2021

Variables	**List of Kebeles in the Selected District**												
	Shewoch Tera		Gizana		Angote		Yifag		Birra		Total		X2- value
Sex of the hh (%)	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	11.33*
Male	79	98.75	79	98.75	76	95	72	90	78	97.5	384	96	
Female	1	1.25	1	1.25	4	5	8	10	2	2.5	16	4	
Access to Market Information (%)													36.04***
Yes	61	76.25	46	57.5	77	96.25	66	82.5	61	76.25	311	77.75	
No	19	23.75	34	42.5	3	3.75	14	17.5	19	23.75	89	22.25	
Access to Irrigation (%)													4.21
Yes	75	93.75	79	98.75	75	93.75	77	96.25	74	92.5	380	95	
No	5	6.25	1	1.25	5	6.25	3	3.75	6	7.5	20	5	
Access to Non/Off-Farm Income (%)													23.3***
Yes	46	75.5	42	52.5	37	46.25	18	22.5	36	45	179	44.75	
no	34	42.5	38	47.5	43	53.75	62	77.5	44	55	221	55.25	
Access to Mobile Phone (%)													38.2***
Yes	45	56.25	36	45	16	20	14	17.5	28	35	139	47.75	
No	35	43.75	44	55	64	80	66	82.5	52	65	261	65.25	
Access to Credit (%)													27.5**
Yes	56	70	52	65	45	56.25	54	67.5	60	75	267	66.75	
No	24	30	28	35	35	43.75	26	32.5	20	25	133	33.25	

$\chi 2$ =Chi square test

Of the total sample respondents, more than 95% are informed about marketing features through various sources of information. It implies that garlic producers are determining profitable marketing outlets for their products. Given that access to credit, with its significant figure, indicates that farmers have the best room to select and determine their best marketing option from the given alternatives, they must use it.

Of the respondents, 20.50% were illiterate, 41.75% read and write, 17.75% of primary school (1-6), 12.75% were from secondary school (7-12), and 7.25% had a certificate above. 97% of farmers confirmed that the trend of garlic production for the last four years was increasing. The primary source of credit was regional credit and saving institutions. In the case of transportation to transport garlic by garlic producer farmers, 3.5% of farmers transport garlic product by the workforce, 43% with back animals, 2% of farmers with the vehicle, and 51.5% of farmers transport with all means of transportation. With the 1%, 5%, and 10% significant levels, there was a significant mean difference between each sample kebele in terms of the number of extension contacts, education level, mode of transportation, marketplace accessibility, and the price trend of garlic over the last four years Table 4.

Table 4. Demographic and socioeconomic characteristics of the sampled households (categorical variables).
Source: Own Analysis 2021.

Variables	**List of Kebeles in the Selected District**												
	Shewoch Tera		Gizana		Angote		Yifag		Birra		Total		X^2
Education Level (%)	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	32.43**
Illiterate	18	22.5	16	20	13	16.25	17	21.25	18	22.5	82	20.5	
read and write	43	53.75	21	26.25	33	41.25	42	52.5	28	35	167	41.75	
primary school (1-6)	8	10	17	21.25	18	22.5	14	17.5	14	17.5	71	17.75	
secondary school (7-12)	5	6.25	19	23.75	10	12.5	4	5	13	16.25	51	12.75	
certificate and above	6	7.5	7	8.75	6	7.5	3	3.75	7	8.75	29	7.25	
Number of Extension Contact (%)													52.26***
Weekly	63	78.75	71	88.75	44	55	60	75	48	60	286	71.5	
once in two Week	7	8.75	5	6.25	6	7.5	15	18.75	11	13.75	44	11	
Monthly	10	12.5	4	5	30	37.5	5	6.25	21	26.25	70	17.5	
Means of Transportation (%)													25.61*
Workforce	7	8.75	7	8.75	0	0	0	0	0	0	14	3.5	
back animals	32	40	35	43.75	35	43.75	36	45	34	42.5	172	43	
Vehicle	2	2.5	1	1.25	0	0	3	3.75	2	2.5	8	2	
all means of transportation used	39	48.75	37	46.25	45	56.3	41	51.3	44	55	206	51.5	
The Trend of Garlic Production (%)													11.18
Increasing	77	96.25	78	97.5	77	96.25	77	96.25	79	98.75	388	97	
Decreasing	2	2.5	2	2.5	0	0	3	3.75	0	0	7	1.75	
both increasing and decreasing	1	1.25	0	0	3	3.75	0	0	1	1.25	5	1.25	
Sources of Credit (%)													17.88
ASCI	75	93.75	76	95	78	97.5	80	100	75	93.75	384	96	
Cooperative	1	1.25	1	1.25	0	0	0	0	1	1.25	3	0.75	
governmental banks	4	5	3	3.75	0	0	0	0	4	5	11	2.75	
private banks	0	0	0	0	2	2.5	0	0	0	0	2	0.5	
Market Place Accessibility (%)													197.1***
Addis Zemen	63	78.75	80	100	8	10	18	22.5	25	31.25	194	48.5	
Yifag	13	16.25	0	0	58	72.5	50	62.5	38	47.5	159	39.75	
Woreta	4	5	0	0	14	17.5	12	15	17	21.25	47	11.75	
The trend in the price of garlic during the last four years (%)													22.74**
Increasing	78	97.5	78	97.5	71	88.75	79	98.75	79	98.75	385	96.25	
Decreasing	2	2.5	2	2.5	9	11.25	0	0	1	1.25	14	3.5	
both increasing and decreasing	0	0	0	0	0	0	1	1.25	0		1	0.25	

χ2 =Chi square test

Education is the main ingredient that helps to decide on any issue appropriately. Of the total sample of farmers, more than 40% of them can read and write. Having this confirmation, garlic products' production and commercialization are undertaken systematically for the achievement expectation profit of farmers.

Garlic Market Channel

The sample households were interviewed about the types of the market channel they preferred to sell their garlic production based on accessibility and maximum profit received. Therefore, they responded that they used different market channels to sell their garlic production. These marketing channels were listed collectors, wholesalers, retailers, and consumers. Those marketing channels are primarily preferred in mixing and separately.

As compared with the market channel of garlic products [23], confirmed that wholesalers, collectors, retailers, and consumers received the majority of the tomato product [17]; found that wholesalers, collectors, retailers, and consumers are the main marketing channels for a vegetable product similar to the current garlic marketing channel; in supporting the current garlic marketing channel [24], initiated that wholesaler, cooperatives and collectors are the significant market outlet for sesame product [19]; stated that consumer market channel is the primary market for vegetable producers in their study area. The current study identified that marketing

Out of these four main market channels preferred by households, wholesalers were the preferred market channel by 93.75% of the garlic producers' households [18]. The wholesale market channel is the main influential marketing channel for vegetable products in their research area. The second most marketing outlet was the collectors, preferred by 65.25% of garlic producers' households; the third and fourth marketing channels were retailers and consumers were preferred by 57% and 40% of garlic producers' households, respectively, as presented in Table 5.

Table 5. Garlic farmers favoured the following four main marketing channels.
Source: Own Analysis 2021

Market Channel for Garlic								
Channel Selection by the Household	Collectors		Wholesalers		Retailers		Final Users/buyers	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Yes	261	65.25	375	93.75	228	57	240	60
No	139	34.75	25	6.25	172	43	160	40
Total	400	100	400	100	400	100	400	100

%=indicate percent

Farmers demanded to sell large quantity products and make a mass profit at one time. Wholesalers buy a more significant amount of product from the four main market outlet options and provide acceptable profit for sellers. As a result, garlic producers are the preferable outlet option. Compared to the current study of marketing channels conducted in Ethiopia, wholesalers and retailers are the main identified market channels for garlic products in the Madhya Pradesh [25]; In addition [26], Identified wholesalers, retailers, and consumers' marketing channels are as a critical marketing channel during their investigation of the market efficiency of garlic crop in Bangladesh. Wholesalers and processors are the main marketing channels for garlic products in Tanzania [27].
The Factors Influencing Market Outlet Selection shall be underlined for consistency.

Table 6. Determinants Influencing Garlic Producers' Market Outlet Selection.
Source: Own Analysis 2021.

Covariates	**Collectors**		**Wholesalers**		**Retailers**		**Final Users/buyers**	
	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
_cons	-1.51*	0.84	0.81	1.36	-2.56**	0.84	-0.86	0.84
Qtygp	0.107***	0.04	-0.12*	0.06	0.205***	0.04	0.151***	0.036
Fextc	-0.06	0.09	0.11	0.15	-0.12	0.09	-0.24***	0.09
Landing	-0.09	0.07	-0.20**	0.10	-0.09	0.06	-0.03	0.07
Acredit	0.00	0.00	0.00	0.00	0.00	0.00	-4.95e-06	0.00
Lapric	0.0001*	0.001	0.00	0.00	0.00	0.00	-0.00	0.00
Acmarkt	-0.378**	0.158	0.295	0.248	0.14	0.154	0.003	0.16
Mdist	-0.027	0.020	0.021	0.029	-0.029	0.020	0.008	0199
Expr	0.006	0.006	0.021**	0.010	0.023***	0.007	0.027***	0.007
Edu	0.151**	0.063	-0.077	0.095	0.073	0.062	0.186***	0.063
Oxen	0.065	0.096	0.060	0.144	-0.283***	0.095	-0.174*	0.097
Sex	-0.602**	0.272	0.239	0.361	0.330	0.248	0.117	0.245
Income	-0.180	0.145	0.262	0.228	-0.141	0.142	0.207	0.144

Note: Statistical significance is indicated by ***, **, and * at 1%, 5%, and 10%, correspondingly. Coeff – Coefficient, SE - standard error.

Predicted probability = 60.0 93.7 65.3 56.9 gap is needed

That means garlic producers have a 60.0% probability of selecting collectors market outlet, 93.7% probability in selecting wholesalers market outlet, 65.3% probability in selecting retailers market outlet, and 56.9% probability of selecting consumer market outlet. It is the exact probability value computed from the fitted data.

Joint probability (success) =23.61% and joint probability (Failure) =0.15%
Number of draws =5, Observation =400, and Log Likelihood= -739.43387
Wald chi2 (χ2) (48) = 256.52, and Prob > chi2 (χ2) = 0.0000***

Matrix for expected association =,
/atrho21. -.255, /atrho32. -.156
/atrho31. -.033, /atrho42. .058
/atrho41. -.269, /atrho43. -.164
rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: Likelihood ratio test
Chi2 (χ2) (6) = 18.6218, Prob > chi2(χ2) = 0.0049.

The data finely explained by the model as the Wald (χ2) (48) =256.52 value indicates, that Prob > chi2=0.0000 was significant at the 1% significance level, indicating that the model subcategory of coefficients is jointly significant, and that the independent variable's explanatory power is sufficient. Moreover, the model's likelihood ratio test results chi2 ((χ2) (6) = 18.6218, Prob > chi2 (χ2) = 0.0049. at a 1% significance level, it is statistically significant. This showed that the disturbance term's reliance (independence of market channel select) is ruled out, and strong joint correlations for two expected coefficients across the model's equation. The likelihood ratio test of null hypothesis of the independence between market channels select choice (rho (ρ)21 = rho(ρ)31 = rho(ρ)41 = rho(ρ)32 = rho(ρ)42 = rho(ρ)43 = 0: is significant at 1% level of significant. As a result, the null hypothesis that all rho (ρ) values are mutually equal to zero (0) is rejected; this indicates the model's goodness of fit. As a result, the likelihood ratio statics represent disparities in market outlet selection behaviour among garlic producer farmers. When viewed separately, the ρij values reflect the degree of correlation between each pair of dependent variables. The ρ31 association between collector channel and retailers' channel and the ρ41 association between collectors' channel and consumer channel are positively dependent and significant at the 1% significance level, which indicates a good association between collectors' channels and retailer channels and collectors' channel with consumer channel table 6 above. In the study district, garlic producers in marketing used retailers' channels to replace collectors' channels and consumers' channels to replace collectors' channels.

According to the simulation results, garlic producers are more likely in select collectors, wholesalers, retailers, and consumer market channels, as the value showed 60.0%, 93.7%, 65.3%, and 56.9%, respectively. When compared to the probability of preferring collectors' market outlet option (60.0%), the likelihood of choosing consumers' market outlet option is low (56.9%), wholesalers' market outlet option (93.7%), and market channel choice for retailers (65.3%). There is good evidence to recommend that the availability and probability of consumer market options is a dare. Producers were interested in preferring the wholesale market option compared to other marketing options. Households are more likely to select the four-market outlet option jointly based on the combined likelihood of success or failure of preferring the four-market outlet option. The possibility that households will mutually choose the four market outlets option 23.61% is better than their failure to prefer them (0.15%) jointly. From twelve independent variables in the multivariate probit model, five variables significantly affect collectors market outlet; at the 1%, 5%, and 10% levels of significance, three covariates significantly influence wholesalers market outlet, three covariates significantly influence retailer market outlet, and five covariates significantly influence consumer market outlet. Quantity of garlic production (Qtygp): The results show that the quantity of garlic produced has a statistically significant positive impact on the probability of selecting a collector, retailer, and consumer market outlet at a 1% significance level, as well as it has a statistically significant adverse impact at a 10% significance level on wholesalers' market outlet selection. It means that the more garlic a farmer produces, the more likely he or she is to sell to collectors, retailers, and consumers and less likely to sell to wholesalers. The positive coefficient also suggests that households are becoming more connected to three market channels (collector, retailer, and consumer). Farmers who sell their products to three market outlets can generate a more significant profit margin. Similarly to this finding [28], stated that the number of groundnuts produced positively and significantly impacts the chance of choosing the outlets in the wholesale and retail market [29]. Also, conclude that the volume of tomatoes produced significantly influences farmers' market channel choice.

Sex of households (Sex): At a 5% significance level, the sex of the households was adversely and significantly related to the collector outlet. It implies that being male is not guaranteed to sell their garlic to the collector market. As a result, while most females are faster than males, males had fewer opportunities to sell garlic to various market outlets. In contrast to this finding [30], the probability of a collector market outlet is strongly influenced by the gender of the households [31]. Furthermore [32], reported that the sex of the households significantly affects the decision to choose the market channel of households. Household Education Level (Edu):

At a significant level of 5 and 1%, household education has a positive and significant effect on the probability of collector and consumer market outlets, respectively. Because more educated farmers have become information seekers than non-educated farmers, they are more likely to sell garlic to collectors and consumers. This finding is supported by [33], The educational status of the household head had a substantial impact on collectors and consumers' market outlets. In addition [29,32] confirmed that households' education significantly affects the decision about the choice of the market channel of producers.

Farming Experience (Exper): At 5% and 1% significance levels, agricultural experience had a positive and substantial impact on the chance of choosing a wholesaler, retailer, and consumer market outlet. This study revealed that more experienced garlic producers were likelier than less experienced farmers to deliver garlic to wholesalers, retailers, and consumer outlets. Farmers who have been active in garlic production and selling for a long time want to change their market links to various market outlets, searching for innovative marketing avenues to boost sales or get better prices to maximize farm profits. The link also suggests that more experienced farmers were more knowledgeable about the costs and benefits of various garlic marketing options. Similar to this finding [29,31] conclude that farming experience significantly influences the market channel choice of farmers. Opposing these findings [30], the chance of choosing wholesalers and retailers' market outlets is negatively influenced by the farming experience. Lagged market Price of garlic (Lapric): At a 10% level of significance, lagged market price is positively and strongly associated with selecting a collector's market outlet. Farmers were more likely to sell garlic to collectors' market outlets since the lagged price of garlic was satisfactory, which has a positive sign. It may be because the collector outlet is nearby the farmer's living place and offers a high price for garlic products compared to another outlet, which encourages farmers to choose collector outlets. Therefore, market outlets that offered high prices for garlic last year induced farmers to supply more garlic volumes to the collector outlet [32]. Confirmed that lagged price significantly affects the market channel choice decision of producers.

Land Allocated for garlic Production (Landag): At a 5% level of significance, farmers who allotted more significant acreage for garlic production were negatively and noticeably associated with wholesalers' outlets. As a result of this finding [31,32] found that the proportions of allotted households' land impacted the chance of choosing wholesalers' market outlets. A farmer with a large amount of land allotted for garlic production would likely sell a smaller number of garlic to wholesalers than a farmer with a small amount of land allotted for garlic production, as indicated by the negative sign on the land-allocated covariate [34].

Extension contacts frequency (Fextc): At a 1% significance level, the number of extension contacts negatively and significantly impacts customer outlet choice selections. Households with more visits with extension agents were less likely to deliver garlic to consumer outlets than those with fewer visits. Extension contact allows farmers to improve their production practices, resulting in increased production, which is more likely to sell to collectors, wholesalers, and retailers' outlets than consumers' outlets [31]. Furthermore [30] conclude that access to an extension contact considerably impacts the outlet choice. Market information access (Acmarkt): At a 5% significance level, market information access harms collectors' channel choices. In the research area, households accessing market information reduce the likelihood of preferring a collector market outlet by 37.8%. It means that the more market information/knowledge a household has, the better they are to choose wholesalers' market outlets for bulk selling and retailers' and consumers' market channels for maximum revenue. According to this finding [34,35] market information access has a substantial and negative impact on the selection of the agricultural farmers' market outlets. Number of Oxen owned (Oxen): At 1% and 10% levels, the ox owned has a negative and significant impact on the likelihood of choosing retailer and consumer market channels. It means that when the number of oxen held by households' increases, the likelihood of preferring a retailer and consumer market channel becomes taken down, and they may be able to produce more garlic. They have a chance to select collectors' and wholesalers' market channels. Moreover, many factors influence the producers' choice of outlet: the major ones are the absence of constant market preference, mediocre quality management, minimal product value addition, and lack of trade regulatory framework for all actors, especially for farmers.

Impact

The impact of the present work broadly discusses the status of farmers' market channel choice in garlic product evidence from farmers' market preferences. Conducting a market channel analysis encourages garlic producers to consider how the value and price of the product add to their final product or service and to select a more efficient market with a lower cost-optimized marketing approach to maximize output/profit and minimize marketing cost—measured and interpreted the profitability and sustainability of garlic products for all actors directly involved in garlic production and marketing. Generation through direct value-added and profitability

indicators, and income distribution, can be calculated. Gathering Information on the amount of garlic sold/purchased, the price offered by each market channel, marketing approach, time of sale, and profit margin was collected in farmers' market channel choice to identify the choice of the leading market outlet for garlic product and their determinants.

Economic Impact

During the survey, garlic producers identified collectors, wholesalers, retailers, and consumers' marketing outlet choices. More than 93% of garlic producers preferred wholesalers' market outlet choice from these four market outlet choices considering the amount of sale and maximum profit as a choice indicator, and more than 65% of garlic producers' farmers preferred collectors' outlet choice.

To sell their products to the markets and acquire reasonable profit, garlic producers' farmers must choose the right market channel. Selecting the right markets is critical to each garlic trading actor through numerous market channels, such as choosing the one with the most significant relative gain. When there are no different marketing options for garlic producers, producers are limited in their farm gate markets. Identifying garlic marketing channels takes the opportunity to develop farmers' winning strategies and evaluate garlic market options among different alternatives.

- Farm profits for individual garlic producers are quantified
- Profitable garlic marketing channels are identified.
- The economic and medicinal value of garlic products are estimated
- The amount of garlic production is valued, and the potential for garlic production and opportunities are identified.
- The market linkage between producers and different actors is created

Policy Impact

Understand linkages and dependencies between different activities and areas in the marketing, selecting the central market channel that increase the bargaining power in meeting a comprehensive benefit from the sale of garlic product. Smallholder garlic producers must select high-value market options, such as garlic exporting and processing marketing channels, to maximize their profit.

- The types of improved garlic varieties that will be produced are recommended.
- The participation of stakeholders in various garlic value chain activities is highly recommended.
- Motivation for farmers and government institutions is forwarded
- Correct decisions are endorsed for various marketing channels.

Regional Impact

Analysing the current garlic market chains is essential in transforming traditional hand-to-mouth garlic production into market-oriented or modern garlic production in the production Region.

The contributions of garlic production and marketing are valuable; it leads to the development of the Region's GDP in the agricultural sector's vegetable share.

- The demand and supply of garlic products can be balanced in the Region.
- Annual garlic productivities will increase.

Conclusions

Numerous covariates are analysed with the econometrics model to evaluate whether they positively or negatively influence garlic producers' market outlet choice decisions. The econometric model result shows that the amount of garlic produced, extension contact frequency, land allotted for garlic production, lagged market price, market information access, experience for garlic production and marketing, level of education for garlic producers, the number of oxen owned with garlic producer farmers, and the sex of the household has both positive and negative effects on garlic producers' market channel selection decisions. Based on this finding, the result allows the opportunities to set the solution for the negative influence of the covariates. Agricultural extension experts, research centre, and universities had better focus on garlic's productivity. The gender-inclusive production system can be advisable for sustainable garlic production and market supply. It is also essential to link farmers with the most significant market outlets, wholesalers, and collectors, to improve their farm income and livelihood.

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Conflict of interest
There are no conflicts of interest to declare.

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