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Optimizing Agricultural Production with Socioeconomic Considerations: A case Study from Palestine

تحسين الإنتاج الزراعي باعتبارات اجتماعية و اقتصادية: دراسة حالة من فلسطين

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Abstract: Agriculture is not only the main source of income to most Palestinian families; it is also the link to connect them to their valuable land and water resources. Farmers seek assistance from agronomists and decision makers to cultivate the proper products. In this study, the best selection of agricultural crops is addressed in the multiple-objective context. The study deals with three conflicting objective functions: net benefit, agricultural production, and labor employment. Four-stage procedure is adopted combining multiple-objective optimization, simple valuation methods, cluster analysis, and multiple criteria decisions making (MCDM) methods. Pareto optimal curves are used to evaluate the marginal prices of both land area and Labor Day. The theories of utility and benefit cost are applied to rank the non-dominant alternatives. Two MCDM methods, namely weighted goal programming and step methods, are employed in the evaluation. The above methodology is applied to the case study of Qalqilya District in which irrigated agriculture under semi-arid conditions prevails. The results show that Pareto optimal is a powerful tool to determine the marginal price of non-monetary commodities. It is also found that the average annual net benefit, agricultural production, and labor employment for the cultivated area are $941,423, 3,288 tons, and 14,671 days, respectively, in the best compromise plan. The inclusion of socioeconomic considerations in decision making on agricultural systems is crucial for their sustainable development.

Keywords: Multiple criteria, Decision making, Agriculture, Planning, Optimization.

المستخلص: تشكل الزراعة مصدر الدخل الرئيس للعديد من العائلات الفلسطينية، كما أنها الرابط الأقوى مع أراضيهم ومصادرهم المائية النفيسة. يسعى المزارعون للحصول على مساعدة المهندسين الزراعيين وصناع القرار لزراعة المنتجات المناسبة. تتناول هذه الدراسة آلية اختيار أفضل المحاصيل الزراعية بناء على عدة اعتبارات وبتحقيق أهداف متنوعة. تسعى هذه الدراسة لتحقيق ثلاثة أهداف متباينة في آن واحد: صافي المنفعة، الإنتاج الزراعي، وتشغيل العمالة. تعتمد طريقة العمل على أربع مراحل: التحسين متعدد الأهداف، طرق تقييم البدائل البسيطة، التحليل العنقودي، وطرق اتخاذ القرارات متعددة المعايير. تستخدم منحنيات باريتو المثلى لتحديد الأسعار الهامشية لكل من مساحة الأرض ويوم العمل. تطبق نظريات الخدمة والمنفعة مع التكلفة لترتيب البدائل غير المفضلة. تستخدم طريقتين لاتخاذ القرارات متعددة المعايير في هذه الدراسة وهما: برمجة الهدف حسب أهميته ووزنه إضافة إلى طريقة خطوة تلو خطوة بحسب الأفضلية عند متخذ القرار. تطبق هذه المنهجية لدراسة حالة محافظة قلقيلية في الضفة الغربية من فلسطين، حيث

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تسود الزراعة المرويّة والأجواء شبه الجافة. تشير النتائج إلى أن منحنيات باريتو المثلى خير أداة لتحديد السعر الهامشي للسلع غير النقدية. من أجل خطة لأفضل الحلول الهندسية لزراعة المحاصيل الأنسب، توضح النتائج أن متوسطات صافي المنفعة السنوية، الإنتاج الزراعي، وتشغيل العمالة هي 941423 دولارا أمريكيا، 3288 طنا، و14671 يوم تشغيل، على الترتيب. يعتبر إدراج الاعتبارات الاجتماعية والاقتصادية في صنع القرارات بشأن الأنظمة الزراعية أمرا حاسما وضروريا لتحقيق أهداف التنمية المستدامة لتلك الأنظمة .

الكلمات المفتاحية: معايير متعددة، صنع القرار، الزراعة، التخطيط، التحسين، فلسطين.

INTRODUCTION:

Agricultural systems in developing countries are economically infeasible as they generally work far below their potential (Raju and Kumar 1999). In the past, agriculture used to be the largest sector of the Palestinian economy, generating 22% of the gross domestic product (GDP) in the West Bank and Gaza Strip and providing employment to 15% of the population (Butterfield et al 2000). In Palestine, the unemployment rate exceeded 22% for the year 2007 (PCBS 2008a) and approached 27% in 2015 (PCBS 2015). Investigations showed that the agricultural sector contributed to only 4% of the GDP between 2013 and 2015 (ARIJ 2015; UNSCO 2015). The services, construction, and information technology sectors dominate the Palestinian economic performance at the expense of agriculture and other major contributors (see ARIJ 2015). This decline in agricultural activities necessitates using new techniques and programs for agricultural sector planning, replenishment, and development. This paper aims to examine possible alternatives and potential solutions to support sustainable development of the agricultural system and provide tools to cope with the economic recession in the Palestinian market such that took place in the last few years.

Palestinian families rely on agriculture which supplies basic food needs, creates job opportunities, and generates a secondary income source, (Butterfield et al 2000; ARIJ 2015). However, Palestinian agriculture is constrained by available land and water as well as access to local and international markets (see Butterfield et al 2000; ARIJ 2015). Political constraints control and mitigate agricultural production for Palestinian farmers. Material and equipment needed for agricultural production are controlled, constrained, and sometimes prohibited to access the Palestinian markets by the Israeli occupation. Exporting Palestinian products to regional markets have undeniably been a dream to local farmers, making the agricultural system neither sustainable nor reliable (ARIJ 2015).

In effect, the constraints mentioned above have been the object of political conflict, as Israeli authorities have limited accessible land, water, and markets to Palestinians. This makes the case study of Palestine a unique and interesting case to address challenging environments of agriculture at which socioeconomics, politics, and science and technology meet. Scientists and agronomists should have created novel techniques and tools that lead to sustainable development through the proper planning and management of the agricultural system in Palestine .

Butterfield et al (2000) developed a linear programming model to maximize the total net agricultural profit by choosing the appropriate crops and the corresponding monthly allocation of available land and water. There was no labor constraint in the Butterfield et al (2000) model as Palestine is a labor abundant country but not in the agriculture sector. The results showed that both water and export markets place major limits on the agriculture in Palestine. A total of 405 million cubic meters of water was needed in addition to what is available now in order to realize the full potential of Palestinian agriculture (Butterfield et al 2000). This figure was based on the present irrigation technology, existing water transportation infrastructure, current amount of available agricultural land, and unlimited export markets. In short, Israeli control over the water resource is a major constraint on Palestinian agriculture (see Butterfield et al 2000; Anayah 2006; ARIJ 2015) .

In general, multiple criteria decisions making (MCDM) models have been excessively utilized in various decision-support applications including computer technology, management, ecology, agriculture, medicine, tourism, and many other areas. Many models, e.g., PROMETHEE, MAUT, ELIMINATION, DEX, and EXPROM, have been widely used to assess sustainability of agricultural systems and support decision processes for farm planning and management. These approaches require software capabilities to find optimal solutions and are relatively complicated as huge amounts of multidimensional data are typically needed (Talukder 2016). There is a dire need to simple models that are designed specifically for the case of study so that creative solutions to current challenges for the Palestinian agricultural system must be found out .

Raju and Kumar (1999) examined the selection of the best compromise irrigation plan in the multiple-objective context at Andhra Pradesh of India. The study dealt with three conflicting objectives: net benefit, agricultural production, and labor employment for 16 crops. Two MCDM methods, namely PROMETHEE-2 and EXPROM-2, were employed in the evaluation. It was found that the best plan indicated that net benefits, agricultural production, and labor employment per hectare for the culturable area were, on average, 8,980 rupees (= $225), 3.73 tons, and 242-man days (Raju and Kumar 1999). Sahoo et al (2006), for instance, developed linear programming and fuzzy optimization models to manage the land-water-crop system of Mahanadi-Kathajodi delta in India and get the best cropping patterns. It was shown that linear programming models work well with single criteria decision systems while MCDM systems require fuzzy optimization models .

Agha et al (2012) developed a crop planning to solve a MCDM problem in Gaza Strip of Palestine using analytic network process method. Eight major types of crops were compared using seven main criteria regardless of crop requirements for land and water. The focus of the study was to show how the government can manage the agricultural sector in general, but interventions from the private sector or farmers were completely ignored. The economics dominated all other evaluation criteria, and therefore, export crops were at the top of the optimal crop list. Sandhyavitri et al (2016) had used the same method of Agha et al (2012) at Riau Province in Indonesia. The aim was to assist the local government select the best irrigated area for rice production out of four competing areas. The selection was based on five ordered criteria: institutional, technical, economic, social/cultural, and environmental criteria .

Hidayati et al (2017) used the DEX evaluation model to help decision makers determine crops to be planted during the dry season. Many evaluation criteria were used such as knowledge, budget, land area, and human resources. For the case study, six vegetables were selected: tomato, cucumber, red pepper, mustard greens, corn, and green beans. Vegetables to plant were tomatoes, cucumbers, and corn according to corresponding value set determined by decision makers in terms of gains and implementation. The model supports farmers or non-farmers to make proper decisions for the best selection of vegetables to plant.

Nikoloski et al (2018) have recently developed a “transparent” model used for regional planning of agricultural systems for all levels of decision making from governments to farmers. The transparency of this white-box model enables farmers to understand results and evaluate consequences of decisions made. However, the model of Nikoloski et al (2018) did not consider other agriculture branches and was developed for a certain location and type of farming .

In effect, there are many key points to raise here:

1. All management levels should have been involved in the decision-making process as indicated by Nikoloski et al (2018). This is unlike the approach of either Agha et al (2012) and Sandhyavitri et al (2016) which focused on the governmental level only, or the approach of Hidayati et al (2017) which considered the farm level.

2. Not all major types of crops can successfully grow as shown in the case of Gaza Strip (Agha et al 2012), and therefore, specificity is necessary to attain realistic solutions.

3. Using major types of crops by Agha et al (2012) entails that average values (not actual) of crop specifications are used. Unlike the median value, the average value is typically a biased and non-realistic statistic that might not necessarily exist in the population .

4. Using one crop only, e.g., Sandhyavitri et al (2016), makes the problem easier to solve, yet cultivating a variety of crops is important to secure food variety for Palestinians given the limited water and land resources (see Butterfield et al 2000; Anayah 2006).

5. Determining the major types of crops is still challenging, and therefore, identifying the specific crops was recommended by Agha et al (2012). It is the approach recent studies, e.g., Hidayati et al (2017) and Nikoloski et al (2018), have effectively adopted .

6. Despite the limitations of the Nikoloski et al (2018) approach, it is still applicable to the study area and supports robust communication between the different management levels in the agricultural system of Palestine .

As a result, the model proposed in the present study should be simple, reliable, and applicable to the local environment of Palestine given the limitations of data and resources as well as the utilization of technology and creativity. The main objectives of this paper are to calculate the marginal price of land area and Labor Day, to characterize and rank the non-dominant alternatives, and to select the best compromise agricultural plan. The developed model serves as a means of analysis that can definitely help decision makers develop the agricultural sector in the Palestinian economy. The proposed procedure can be efficiently extrapolated to promote sustainable and reliable agriculture in economies of other districts or developing countries.

METHODOLOGY:

In this paper an agricultural planning model is developed incorporating multiple criteria optimization algorithm that helps decision makers select the best compromise agricultural plan. Farmers seek the help of extension agents and engineers working in the agriculture industry to decide what selection of crops to cultivate. In order to get a feasible solution to this important question using the basic steps for benefit/cost analysis, other considerations including resources and production needed have to be precisely identified. This algorithm considers three substantial criteria: net benefit, agricultural production, and labor employment. The MCDM methods are powerful tools to compare different alternatives, conduct a profound analysis, select the best alternative, and examine the applicability of this alternative (Romero and Rehman 2003).

Four-stage procedure is employed to select the best compromise agricultural plan (alternative corresponds to the best tradeoff between multiple objectives). In the first stage constraint method of multiple-objective optimization basically generates non-dominated alternatives. Pareto curves are developed to evaluate feasible sets of objective functions that are obtained by the individual optimization stage. Indirect valuation method is used to evaluate the marginal price of a dunum (1 dunum = 1,000 m2) of land and the marginal price of a Labor Day. Simple valuation methods are employed in the second stage in which two ranking methods are utilized. The utility theory and the benefit cost analysis are used to rank the non-dominant alternatives among each other. Spearman rank correlation coefficient determines the measure of association between ranks obtained by these two different valuation methods. In the third stage, non-dominated alternatives are reduced to a manageable subset with the help of the cluster analysis. In the fourth stage, two MCDM methods, namely the weighted goal programming (WGP) and the step method (STEM), are used to evaluate and select the best compromise agricultural plan .

Providing accurate information and statistics to the decision makers is a vital requirement in drawing policies and monitoring the progress and development of the agriculture sector. The agriculture statistics report (PCBS 2007) covered the agricultural year 2005/2006, and provided data about the most important statistical indicators from two sides. One side was about the quantitative data that cover the cultivated area by different types of crops, in addition to the productivity of each unit area. While the other side dealt with the agricultural economy, including the production values for each plant, in addition to the economic statistical indicators such as the costs of intermediate consumption and the value added to the agriculture sector (see PCBS 2007). The above methodology is applied to the case study of Qalqilya District in the West Bank of Palestine. In the study area, irrigated agriculture dominates, semi-arid climate prevails, and challenging environment exists. The water and land resources in the study area are constrained with physical and political limitations .

STUDY AREA:

Geography and Demography:

The Palestinian territories, i.e., West Bank and Gaza Strip, are situated between the Mediterranean Sea and the Jordan River and Dead Sea between 29° and 33° North latitude and 35° and 39° East longitude (PIALES 1996). The West Bank is divided into eleven districts: Bethlehem, Hebron, Jenin, Jericho, Jerusalem, Nablus, Qalqilya, Ramallah and Al-Bireh, Salfit, Tubas, and Tulkarm (Anayah 2006) as shown in Figure 1. Qalqilya is one of the northern districts in the West Bank. Approximately 72,000 Palestinians live in Qalqilya District (PCBS 1999) and annual population growth has always been estimated above the global average. In 2017, the number of populations increased to more than 108,000 people with an average household size of 4.8 persons (PCBS 2018). Elevated unemployment rates are noticed especially among educated young people (see PCBS 1999, 2008a, 2018). Further socio-economic information about Qalqilya District can be easily accessed at PCBS (1999, 2007, 2008a, 2008b, 2015, 2018), MAS (2005), UNSCO (2015), etc.

Agricultural Area:

The West Bank has an area of 5,800 km2, a 130 km length from north to south and between 40 and 65 km in width from east to west (Anayah and Almasri 2009). The total cultivated area in the West Bank is 1,826,096 dunums where 68,321 dunums lie in Qalqilya District of which vegetables occupy 5,864 dunums only (PCBS 2007). The study area in this paper is limited to 1,000 dunums so that the other vegetables can be cultivated on the remaining vegetated area to guarantee food security for the local community. Only five out of the 27 vegetables grown in the study area (see PCBS 2007) will be considered in this paper. This is because these five types are the main vegetables cultivated in this area. The five types of vegetables are cucumber, tomato, cauliflower, cabbage, and potato.

Water Resources:

The principal water resources available to Palestinians include groundwater, springs, and harvested rainwater (UNEP 2003; Anayah 2006; Anayah and Almasri 2009). The surface water is scarce and fully utilized by the Israeli occupation (Abed and Wishahi 1999; Anayah 2006; ARIJ 2015) and thus groundwater is the principal source of water in the West Bank (UNEP 2003; Anayah and Almasri 2009). In 2006, the number of water wells used for agriculture in Qalqilya District was 64 wells that pumped 5,777,400 m3 (PCBS 2006a). The water available for the study area is about 504,364 m3. This information is important since it is the limiting factor to cultivate larger areas as the water resources are out of control for the Palestinians.

Climate:

The climate in the Mediterranean region has four months of hot dry summer and a short mild winter with rain from November to March (Anayah 2006; Anayah and Almasri 2009). The climate in the West Bank can be characterized as hot and dry during the summer and cool and wet in the winter (UNEP 2003; Anayah and Almasri 2009). The climate becomes more arid to the east and south (Anayah and Almasri 2009). Annual rainfall on the central highlands averages 700 mm and becomes less than 100 mm at the Dead Sea (Anayah 2006; Anayah and Almasri 2009). However, great variations in both rainfall amount and distribution exist in the study area (Anayah and Almasri 2009). In 2006, the annual average of the maximum air temperature was 26°C, the annual average of the minimum air temperature was 18°C, the mean relative humidity was 62% and the mean wind speed was 4.6 km/hour in Qalqilya area (PCBS 2006b). These data will be used to calculate the evapotranspiration rate which is required to determine the crop water requirement for each vegetable type. The reader can refer to Allen et al (1998), Anayah (2012), Anayah et al (2013), and Anayah and Kaluarachchi (2014, 2019) for detailed information about the methods to estimate potential and actual evapotranspiration.

MATERIAL AND METHODS:

The study was a cross-sectional study covering an area of about 2000Km2 that was conducted in different cities and villages from the northern governorates in the West Bank; Jenin, Tulkarm, Nablus, Qalqilya, Tubas and Salfit in order to determine the dangerous places (if found). The targeted area was shown in **figure (1).**

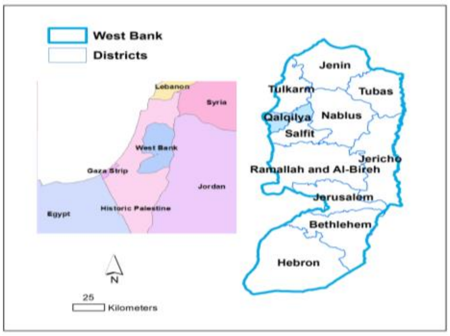

Figure (1): The West Bank districts of Palestine.

MATHEMATICAL MODELING:

Objective (1): Maximization of net benefits:

The net benefits (NetBen) from the cultivated area of different vegetables are obtained by subtracting the cost of water (groundwater) and the production cost from the gross revenue for the different vegetables. Maximization of net benefits can be expressed as shown in Eqn:(1) .

Net Benefit = Revenue - Water Cost - Total Production Cost.

$$Max\ NetBet = \sum_{i=1}^{5} R_i A_i - P_{GW} \sum_{i=1}^{5} (WR_i) A_i - \sum_{i=1}^{5} (PC_i) A_i \qquad \textbf{Eqn. (1)}$$

in which i is the vegetable index [1 = cucumber, 2 = tomato, 3 = cauliflower, 4 = cabbage, and 5 = potato], Ri is the unit gross return from the ith vegetable ($/dunum), Ai is the area of vegetable i (dunum), PGW is the unit groundwater cost ($/m3), WRi is the annual water requirement for the ith vegetable (m), and PCi is the production cost (total cost except water) for the ith vegetable ($/dunum).

Revenue:

PCBS (2007) in its agriculture statistics report for the agricultural year 2005/2006 provided the yield and the market price for the different vegetable types. The revenue can be calculated by **Eqn. (2)** as follows:

$$R_i = Y_i P_i \qquad \textbf{Eqn. (2)}$$

in which Yi is the yield of the i^th vegetable (tons/dunum) and Pi is the market price of the ith vegetable ($/ton). The revenues obtained from each vegetable type are tabulated in **Table (1)**.

Table (1): Revenue obtained from each vegetable type (PCBS 2007).

No.	Vegetable	Market price *$/ton*	Yield *ton/dunum*	Revenue *$/dunum*
1	Cucumber	523	1.5	795
2	Tomato	466	4	1864
3	Cauliflower	483	3.5	1692
4	Cabbage	411	3.7	1521
5	Potato	314	1.8	565

Water Cost:

Although water is an economic good, but water has a unique value for human survival and health. The price of water is considered to be the cost to deliver this water. The price of one cubic meter of supplied water varies widely across the Palestinian territories. The price is determined by the management system of the water service. Therefore, tariff prices are characterized by a wide range; 0.19 $/m^3$ in Qalqilya to 1.65 $/m^3$ in Bethlehem (PHG 2000).

The water requirement for each vegetable type (i.e., crop) should be determined. This section deals with the calculation of crop evapotranspiration (ET_c) under standard conditions. “No limitations are placed on crop growth or evapotranspiration from soil water and salinity stress, crop density, pests and diseases, weed infestation or low fertility” (Allen et al 1998). ET_c is determined by the crop coefficient approach (see Allen et al 1998) whereby the effects of the various weather conditions are incorporated into the potential evapotranspiration (ET_o) and the crop characteristics into the Kc coefficient as shown in **Eqn. (3):**

$$ET_c = K_c ET_o \qquad \textbf{Eqn. (3)}$$

The effects of both crop transpiration and soil evaporation are integrated into a single crop coefficient (see Anayah 2012; Anayah et al 2013; Anayah and Kaluarachchi 2014). The Kc coefficient incorporates crop characteristics as well as averaged effects of evaporation from the soil (see Allen et al 1998). For irrigation and management purposes, average crop coefficients are more convenient than the Kc computed on a daily time step for a certain crop (see Allen et al 1998; Anayah 2012; Anayah et al 2013). Penman equation is used to calculate the ETo (see Allen et al 1998) in the Qalqilya area based on the meteorological status therein. The value of ETo in the study area is 4.35 mm/day. In addition, the growing season for each vegetable type should be determined in order to calculate the water needed on an annual basis (Allen et al 1998; Anayah 2012; Anayah et al 2013). The results of these calculations are summarized in **Table (2).**

Table (2). Water requirements for the different vegetable types (see Allen et al 1998).

No.	Vegetable	Growing season *day*	Crop coefficient K_c	ET *mm/day*	Water requirement *meter (depth)*

1	Cucumber	180	1.15	5.003	0.900
2	Tomato	150	1.20	5.220	0.783
3	Cauliflower	130	1.05	4.568	0.590
4	Cabbage	120	1.05	4.568	0.548
5	Potato	150	1.15	5.003	0.750

Production Cost:

The production cost includes the total cost except the cost of water which was found earlier. The production cost includes the capital costs and the running costs. The capital cost includes the (initial) irrigation system cost. The running costs include cultivation, fertilizers, pesticides, seeding, and labor costs. These calculations are made with the aid of many studies occurred in Palestine, e.g., EQA et al (2004) and MoA et al (2004). The production cost for each vegetable type is illustrated in **Table (3).**

Table (3): Production cost for each vegetable type in $/dunum (see EQA et al 2004; MoA et al 2004).

No.	Vegetable	Initial cost	Running costs					Total costs
		Irrigation system	Cultivation	Fertilizers	Pesticides	Seeds and seedling	Labor force	
1	**Cucumber**	35	25	70	55	30	180	395
2	**Tomato**	35	25	100	70	65	250	545
3	**Cauliflower**	35	25	75	80	50	170	435
4	**Cabbage**	35	25	70	70	50	160	410
5	**Potato**	35	35	50	45	100	170	435

Objective (2): Maximization of agricultural production:

The total agricultural production (PRODUCT) of all vegetables is to be maximized to securing the demands for food as shown in **Eqn. (4):**

$$Max\ PRODUCT = \sum_{i=1}^{5} Y_i A_i \qquad \textbf{Eqn. } (4)$$

This objective function seems to be similar to the first objective function as productivity indicates profitability. However, this is a political objective to stimulate the model to utilize the maximum permissible area of development. It also indicates the fertility of the soil system and the land area.

According to the PENGON (2003) report, Qalqilya is the first of all Palestinian communities to be entirely sealed by the Israel's apartheid wall. The city area is 3,500 dunums of residential lands and 6,500 dunums of agricultural lands. "The wall has confiscated and isolated 3,750 dunums of land while destroyed another 2,200 dunums for its footprint" (PENGON 2003). This indicates the competition Palestinians experience in order to efficiently cultivate the largest permissible area. Furthermore, almost half of the West Bank's freshwater resources come from the Western Aquifer which rests under Qalqilya (Anayah 2006); Qalqilya may lose at least 13 groundwater wells to the wall (PENGON 2003). The constant challenge for local residents is to use their own land; otherwise, they may lose it.

Objective (3): Maximization of labor employment:

The total labor employed under all vegetable types for the whole year is maximized to increase the level of their economic status. In this paper, the total labor is represented by the total labor days (LABOR) and can be expressed by **Eqn. (5)** as:

$$Max\ \text{LABOR} = \sum_{i=1}^{5} L_i A_i \qquad \textbf{Eqn. (5)}$$

in which Li is the number of labor days required per unit area (day/dunum). Keep in mind that the labor cost per unit area for each vegetable type is given earlier in Table 3. The main vegetable types grown in the Crop Cultivated Area (CCA) are cucumber, tomato, cauliflower, cabbage, and potato. The average daily wage for paid employees in the agricultural sector of the Palestinian territories is approximately $10 per day (PCBS 2008b) during the corresponding agricultural year. Hence, the number of labor days for each vegetable can be easily found in the literature (see EQA et al 2004; MoA et al 2004; PCBS 2008b) as shown in **Table (4).**

Table (4): Number of labor days required for each vegetable type (see EQA et al 2004; MoA et al 2004; PCBS 2008b).

No.	Vegetable	Labor force	Labor wage	Labor days
		$/dunum	*$/day*	*day/dunum*
1	Cucumber	180	10	18
2	Tomato	250	10	25
3	Cauliflower	170	10	17
4	Cabbage	160	10	16
5	Potato	170	10	17

Binding constraints to the objective functions:

The above given objectives are subject to the following constraints:

a. Crop land requirements: The total area allocated for the different vegetables should be less than or equal to the CCA (**see Eqn. 6**).

$$\sum_{i=1}^{5} A_i \leq CCA \qquad \textbf{Eqn. (6)}$$

The total cultivated area (5,864 dunums) grown with vegetables in Qalqilya District is much larger than the CCA in this study which is estimated at 1,000 dunums .

b. Water requirements of vegetables: Annually vegetable water requirements should not exceed the maximum available water from groundwater sources as illustrated in **Eqn (7)**

$$\sum_{i=1}^{5} (WR_i) A_i \leq GW \qquad \textbf{Eqn. (7)}$$

in which GW is the annual maximum available groundwater for agricultural purposes (m^3).

c. Groundwater withdrawal: The total groundwater withdrawals in a year should be less than or equal to the estimated safe yield of the aquifer. Nevertheless, Israeli control over Palestinian water is a major constraint on the Palestinian agriculture (see Butterfield et al 2000; Anayah 2006, ARIJ 2015). In

2006, the number of water wells used for agriculture in Qalqilya District was 64 wells which pumped 5,777,400 m^3 (PCBS 2006a). The water is used to irrigate tress, vegetables, and crops. Allocation of this resource will be based on the area and water requirements. Olive trees are the most dominant trees which do not need water almost at all (rainfed trees), however, the crops grown are often rainfed. Hence, a very large portion of this water goes to irrigate vegetables throughout the entire year. According to simple calculations, the water available for the planning area is 504,364 m^3 .

d. Non zero values: The decision variables should not have negative values (**see Eqn. 8**).

$$A_i \geq 0 \qquad \textbf{Eqn. } (\mathbf{8})$$

Individual Optimization :

Optimization of each individual objective (net benefit, agricultural production, and labor employment) is performed with a linear programming (LP) model that gives the upper and lower bounds for the multiple-objective analysis (Loucks et al 1981). LINGO software is used to perform this task. The extreme bounds for each and every objective function are presented in the payoff matrix of the model as depicted in Table 5. In the payoff matrix, maximum and minimum values that can be obtained by each objective function are denoted ith symbol (+) and (-), respectively. The model code for NetBen objective function in specific, as an example, is attached in Appendix A.

Table (5.): Payoff matrix of the model.

Objective function	Maximization of each objective function		
	NETBEN	***PRODUCT***	***LABOR***
NETBEN	978723+	926704	752712-
PRODUCT	2992	3405+	2573-
LABOR	14533-	14726	16083+
Decision Variables			
A2			643
A3	855		
A4		920	

The model depends on cauliflower in the case of net benefit maximization due to the large net benefit per unit area. It is noticed that tomato has the highest revenue return, yet, the tomato cost, specifically labor cost, is much higher. Therefore, cauliflower is preferred to tomato. In agricultural production maximization case, the model depends on cabbage compared to those in the remaining planning objectives because of its higher yield per unit area with lower water requirement than cauliflower. Similarly, the yield of tomato is larger than that of cabbage, but again tomato cost is much higher. In the labor employment maximization case, the model depends on tomato is more labor intensive than those depend on either cauliflower or cabbage. It should be noted that the water constraint is the binding constraint in this model while the land area is not completely utilized .

To make a decision, there should be a compromise among the three objective functions. From the point view of the farmers, it is better to maximize the net benefit, whilst it is better to maximize the land area (agricultural production) from the point view of the decision makers, management entities, and politicians. However, the Ministry of Labor and socio-economic institutions would prefer to maximize the labor employment due to the elevated unemployment rates noticed recently. Eventually, the decision makers should make a compromise among the different and conflicting objective functions to optimize the social welfare as well as the individual interest. This task is not that easy at all as these qualities cannot be simply turned into monetary equivalents and sometimes many other factors might impact the big picture.

Multiple-Objective Planning:

The multiple-objective planning (MOP) helps solve the problem of simultaneous optimization of several objectives subject to a set of constraints, which are usually linear. The MOP provides a set of acceptable (non-dominated or Pareto optimal) solutions, where none of these solutions is preferred (Romero and Rehman 2003). Others experts such as Professor Bruce Bishop (Personal communication, professor, Utah State University) defined MOP as "a method for quantifying tradeoffs among the objectives over the range of interest." The key question here is: How much of one objective you should give up to gain a unit of increase in another. This tradeoff information should be transferred to some "decision making body;" or it proceeds with additional mathematical procedures for selecting the best scale of projects among a subset of what is called "good" alternatives.

Mathematical basis for MOP:

The initial task of the MOP is to split the solution range out of the solutions where none of the corresponding objective functions, f1 and f2, is optimized. In this discussion, two objective functions (maximization functions) are taken into consideration as shown in Figure 2. In Figure 2, any solution with X less than Xa should be eliminated as the solution with Xa is better regarding to both objective functions; f1 and f2. The same situation is observed for solutions with X greater than Xb. Any solution in between Xa and Xb could be an optimal solution for the problem. This depends on the key question mentioned earlier: how much are you willing to sacrifice with f1, for instance, in order to gain more f2? The alternatives in between Xa and Xb are called "Pareto optimal or non-dominant solutions ".

In general, none of these solutions is better than another because each solution has its own values of objective functions. For instance, if solution A has a higher value of objective function f1 than solution B, this does not mean that solution A is better than solution B. This is because solution A has a lower value of objective function f2 than solution B. Thus, the compromise between the two solutions; i.e., A and B, depends on the weight of each objective function or the preference pertaining to the decision makers. For more details see Loucks et al (1981).

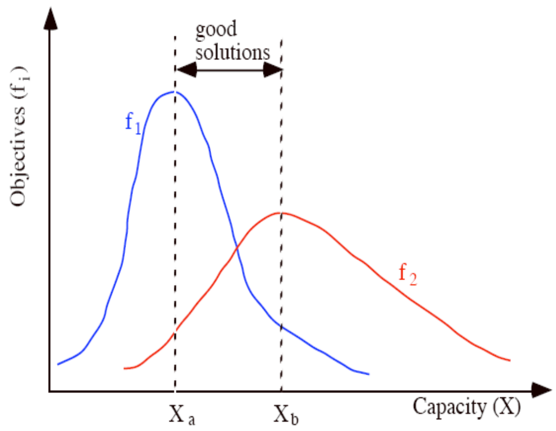

Figure (2): Non-dominated solutions.

Mathematical basis for MOP:

In the previous section, the solution X_a is developed by solving the optimization problem which ignores objective 2 and optimizes objective 1. Similarly, solution X_b is obtained by ignoring objective 1 and optimizing objective 2. When we optimize one objective, ignoring the other, we can obtain a value of the one ignored as well as the one optimized. We could set this as a lower bound on the one ignored and then use some value higher than that bound as an added constraint in our model and get another solution.

One of two things will happen; either the value of the objective being optimized will not change (implying that the new constraint is not yet active) or the objective being optimized will decrease and we will have then obtained one of the solutions between X_a and X_b. In either case our next step is to further increase the lower bound constraint on the objective not being optimized and continue in this fashion until we approach the X_b solution (beyond which we would obtain an infeasible solution). In this manner we can trace the surface of the region identified in **Figure (3)** as good solutions which is identical to the solutions between X_a and X_b in **Figure (2)** The method of generating the solution surface just described here is known as the "constraint method".

In **Figure (3)** we have shifted from the decision variable space (X_i) to the objective function space (f_i). In **Figure (3)** the range of good solutions is revealed but on the objective function space. Any solution with $f1 > f_1^*$ or $f_2 > f_2^*$ will be eliminated. The good solution range is the range from f_1^* to f_2^* which is called the "Pareto curve." In this range, we can obtain Δf_1 additional units of objective one; however, we should give up Δf_2 units of objective two and vice versa. The ratio ($\Delta f_2/\Delta f_1$) is the ratio of the weights of these objectives that reflect the importance of each objective function with respect to the decision maker .

The weight of each objective can be determined relatively in order to get an optimal solution. These weights are subjective to the perception of the decision maker (DM) and the other attributes of the decision. In other words, conflicts may reveal on the table if there are more than one decision maker and the decision is considered based on the different aspects such as spatial and temporal dimension of the decision. Due to the previous reasons, many scientists do not prefer specifying the relative weight of each objective so that the optimal solution will not be biased based on these specified weights. The point O

(f_1, f_2) (see **Figure 3**) is the best solution which means that the ratio $\Delta f_2/\Delta f_1$ is the most appropriate one to the DM. For more details and information, the author refers the reader to Loucks et al (1981).

It should be mentioned that Pareto curve can be a straight line for special and simple cases where the slope is constant. If there are more than two objective functions, the situation is more complicated as you should fix objective function one, for instance, in order to develop the Pareto curve of the other two objective functions. For a different value of objective function one, another Pareto curve will be developed. In general, for more than two objective functions, uncountable number of Pareto curves can be developed. This implies the sensitivity of this method to the perceptions of the designing engineer as well as the DM. Furthermore, this necessitates the interaction between these two key players in order to approach the best optimal solution among the multiple objective functions.

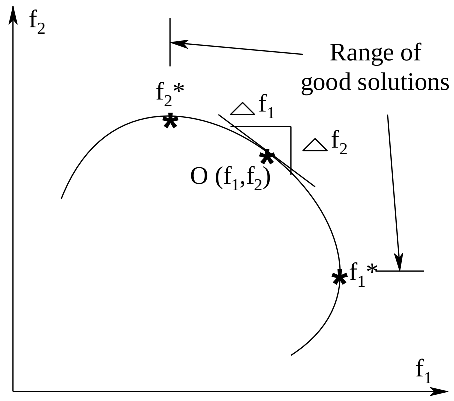

Figure (3): A two-objective problem in the objective function space.

In the economy theory, suppose that one of the objective functions, say f_2, represents the benefit of a resource and the other one, say f_1, represents the quantity of this resource, the slope of the Pareto optimal can be interpreted as the marginal price of this resource. The constraint method is easier to interpret and does not suffer from these mathematical limitations. This method even eliminates the need to specify weights and hence frees designers from subjectivity of key players. It will therefore be used in the following section in order to obtain the different Pareto curves of the corresponding objective functions.

Pareto curve and the Marginal Price:

The Pareto curves are plotted for the three objective functions each two together. However, each Pareto curve is plotted based on a specific value of the third objective function. In order to determine the marginal price for the land area and the Labor Day, a polynomial regression type is selected to represent the relationship between the two objective functions. The polynomial regression is the best one fits to the points obtained from LINGO. At the extremes, further care is required to get a better estimation of the Pareto curve. The non-linearity of the Pareto curve is a result of the constraint on the third objective function value .

The Pareto curve of the net benefit versus the agricultural production is depicted in Figure 4. The model code used to plot this Pareto curve is attached in Appendix B. The marginal price of the land area can be found from the first derivative of the relationship between the net benefit and the agricultural production at a specified level of labor employment (LABOR = 14,630 day) as illustrated by **Eqn. 9** and **Eqn. 10** in the following example:

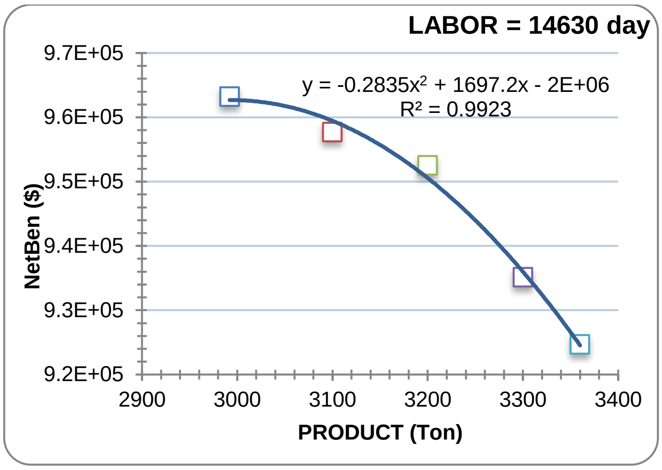

Figure (4): The Pareto curve of the net benefit versus the agricultural production.

$$NetBen = -0.283 \times PRODUCT^2 + 1{,}697 \times PRODUCT - 2 \times 10^6 \qquad \textbf{Eqn. (9)}$$

$$\text{Marginal price (MP)} = \frac{d(\text{NetBen})}{d(PRODUCT)} = -0.566 \times PRODUCT + 1{,}697 \qquad \textbf{Eqn. (10)}$$

For exapmle, at PRODUCT $=$ 3,000 ton, MP $=$ -1 (\$/ton)

However, at PRODUCT $=$ 3,200 ton, MP $=$ -114.2 (\$/ton)

Similarly, the Pareto curve of the net benefit versus the labor employment is plotted as depicted in **Figure (5).**

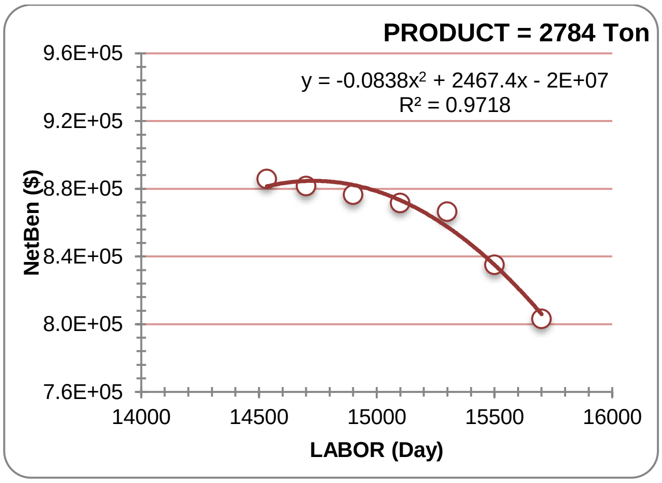

Figure (5): The Pareto curve of the net benefit versus the labor employment

To find the marginal price of the Labor Day, the first derivative of the equation that correlates the net benefit with the Labor Day is determined. The marginal price of a Labor Day at a production level of 2,748 tons **(Eqn. 11)** equals:

$$\text{Marginal price (MP)} = \frac{d(\text{NetBen})}{d(LABOR)} = -0.166 \times LABOR + 2{,}467 \quad \textbf{Eqn. (11)}$$

$$\text{for instance, at LABOR} = 15{,}000, \text{MP} = -23 \text{ (\$/day)}$$

This method is similar to the indirect valuation method used to value public or non-market goods in analogy to market commodities by assessing the cost an individual incurs to utilize these goods (Ahlheim and Fror 2003). The same procedure is followed to plot the Pareto curve of the agricultural production versus the labor employment as shown in Figure 6. This gives an indication of how much labor days you may lose in order to gain one more ton of vegetable. It should be noticed that the water constraint is the binding constraint in all models developed.

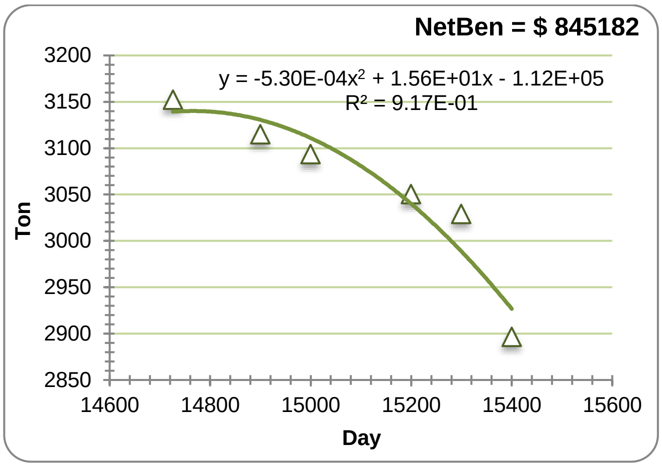

Figure (6). The Pareto curve of the agricultural production versus the labor employment.

Non-Dominated sets of Alternatives:

In the present study the constraint method of multiple-objective optimization is employed. Maximization of the net benefits is selected as the main objective in the constraint method of multiple-objective optimization formulation because of its higher importance attributed. In this method the other two objectives, namely the agricultural production and the labor employment, are placed as constraints in the limitation set .

The non-dominated sets of alternatives are generated by parametrically varying the bounds of the constraints, the i.e., the transformed objective functions of the agricultural production and the labor employment, obtained from the individual optimal solutions. The minimum and maximum values of each objective function are given by the Payoff matrix of the model given in Table 5. The number of generated non-dominated alternatives is reduced to a chosen few by setting an objective function value in between the two extreme values and calculate the values of the other objective functions. As a result, 36 policies labeled P1 to P36 are adopted as shown in Table 6. The general pattern is expected since the net benefits rise up once revenues from production grow and labor costs decline. It is observed that with the increase of the agricultural production and the decrease of the labor employment, the net benefits gradually increase to a maximum level at policy P33 and then decrease a little bit.

It is easier for the DM to see all the different alternatives, i.e., the proposed policies, graphically (**see Figure 7**). The net benefit is directly proportional to the agricultural production whilst both are inversely proportional to the labor employment. It is observed that the net benefit unexpectedly decreases with an increase in the agricultural production in the last three proposed policies. This might refer to the overexploitation of the agricultural productivity, i.e., land area, regardless the net benefit.

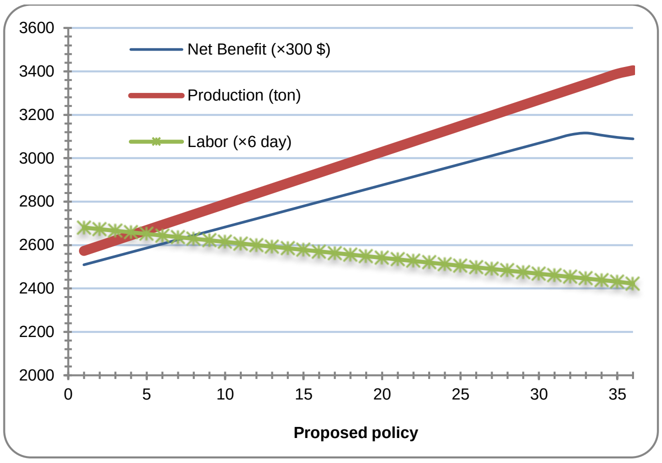

Figure (7): The values of the objective functions for the 36 proposed policies.

Table (6): The proposed policies for the study area.

Policy	Production	Labor	Net benefit
No.	***Ton***	***Day***	***$***
P1	2573	16083	752717
P2	2597	16039	758526
P3	2621	15995	764320
P4	2645	15951	770113
P5	2669	15907	775907
P6	2693	15863	781701
P7	2717	15819	787494
P8	2741	15775	793288
P9	2765	15731	799082
P10	2789	15687	804875
P11	2813	15643	810669
P12	2837	15599	816463
P13	2861	15555	822256
P14	2885	15511	828050
P15	2909	15467	833844
P16	2933	15423	839637
P17	2957	15379	845431
P18	2981	15335	851225
P19	3005	15291	857018
P20	3029	15247	862812
P21	3053	15203	868606
P22	3077	15159	874399
P23	3101	15115	880193

P24	3125	15071	885987
P25	3149	15027	891780
P26	3173	14983	897574
P27	3197	14939	903368
P28	3221	14895	909161
P29	3245	14851	914955
P30	3269	14807	920749
P31	3293	14763	926542
P32	3317	14719	932336
P33	3341	14675	934805
P34	3365	14631	931785
P35	3389	14587	928765
P36	3405	14533	926752

Simple Valuation Methods:

The various techniques for the valuation of public goods are often classified either as direct and indirect valuation methods or in revealed and stated preference assessment methods. Direct valuation methods are typically based on surveys where people are directly asked about their willingness to pay for the public good or the service in question. Indirect valuation methods, however, try to value public or non-market goods in analogy to market commodities by assessing the cost an individual incurs to utilize these goods (Ahlheim and Fror 2003). In this study indirect valuation methods are used in order to evaluate and assess the value of non-market goods such as land area and Labor Day with respect to the net benefit of utilization for these two valuable resources. This is an attempt to correlate the socio-economic aspects to the political and technical backgrounds. This implies how decision-making process is ultimately complex and what efforts are needed to consider the different and conflicting dimensions of the problem to efficiently develop the optimal decision.

Utility Theory:

The utility theory basically suggests a subjective value, or utility, from different choices. Utility theory can be used in both: (1) decision making under risk where probabilities are basically determined and (2) decision making under uncertainty in which probabilities are not obviously stated (Bell et al 1988; Keeney and Raiffa 1993). Under the aspect of growing interdisciplinary projects and consideration of diverse public groups of interest, planning and management become more challenging. It is necessary for an engineer to figure out the solution that satisfies all different groups of interest prior to technical details .

A technique that has to be applied allows for the integration of data such as water quality, quality of life, aesthetics, impact on plants, animal life, etc. The utility theory offers the possibility to process interdisciplinary data. A numerical degree of achievement of a certain goal that allows for direct comparison is assigned to each alternative (see Romero and Rehman 2003). In order to consider non-monetary effects, the utility theory expresses the effects of agricultural planning projects in the form of non-dimensional objectives. Thus, the effects of the different alternatives are precisely expressed.

Because the criteria of a goal are expressed in different units, they must be transformed to enable a reasonable comparison .

The utility theory consists of the following (see Bell et al 1988; Keeney and Raiffa 1993):

a. Determination of the objectives with which the alternatives should be evaluated.

b. Numerical calculation of the objective functions (f_{ij}) if possible, otherwise verbal, with the aid of an evaluation of the actual consequences.

c. Transformation of the objective function values into non-dimensional degrees of goal performance n_{ij} on a specified scale, e.g., 0-10 or 0-1.

d. Determination of weights (αj) according to the relative importance of the goals.

e. Calculation of the total utility using **Eqn. (12):**

$$N_i = \sum_{j=1}^{J} \alpha_j n_{ij} \qquad \textbf{Eqn. (12)}$$

f. Ranking of the alternatives according to their utilities.

Table (7): The non-dimensional degree of goal performance (n) in the utility theory analysis.

Policy	Production	Labor	Net benefit	Total Utility
No.	*Ton*	*Day*	*$*	
P1	0	1	2.2E-05	0.2500
P2	0.029	0.972	0.026	0.2630
P3	0.058	0.943	0.051	0.2759
P4	0.087	0.915	0.077	0.2888
P5	0.115	0.886	0.103	0.3018
P6	0.144	0.858	0.128	0.3147
P7	0.173	0.830	0.154	0.3276
P8	0.202	0.801	0.180	0.3406
P9	0.231	0.773	0.205	0.3535
P10	0.260	0.745	0.231	0.3664
P11	0.288	0.716	0.256	0.3794
P12	0.317	0.688	0.282	0.3923
P13	0.346	0.659	0.308	0.4052
P14	0.375	0.631	0.333	0.4182
P15	0.404	0.603	0.359	0.4311
P16	0.433	0.574	0.385	0.4440
P17	0.462	0.546	0.410	0.4570
P18	0.490	0.517	0.436	0.4699
P19	0.519	0.489	0.462	0.4828
P20	0.548	0.461	0.487	0.4958
P21	0.577	0.432	0.513	0.5087
P22	0.606	0.404	0.538	0.5216
P23	0.635	0.375	0.564	0.5345
P24	0.663	0.347	0.590	0.5475

P25	0.692	0.319	0.615	0.5604
P26	0.721	0.290	0.641	0.5733
P27	0.750	0.262	0.667	0.5863
P28	0.779	0.234	0.692	0.5992
P29	0.808	0.205	0.718	0.6121
P30	0.837	0.177	0.743	0.6251
P31	0.865	0.148	0.769	0.6380
P32	0.894	0.120	0.795	0.6509
P33	0.923	0.092	0.806	0.6565
P34	0.952	0.063	0.792	0.6499
P35	0.981	0.035	0.779	0.6434
P36	1	0	0.770	0.6350
Weights, α_j	0.25	0.25	0.50	

The transformation of the objective function values shown in Table 6 into non-dimensional degrees of goal performance nij obtained in Table 7 is based on **Eqn. (13)** (see Keeney and Raiffa 1993).

$$n = \frac{f - f_{min}}{f_{max} - f_{min}} \qquad \textbf{Eqn. (13)}$$

The weights (αj) of the objective functions are subjective and can be determined based on the importance of each one. The results of the utility theory analysis are summarized in **Table (7).** These weights are typically subjective as they depend on the DM perspectives. In the literature, the net benefit has always been the predominant function compared to the other objective functions. This is because the contribution of Palestinian agriculture sector in GDP had approached 22% in the 1990s (Butterfield et al 2000) and recently dropped to 4% only (PCBS 2015) .

However, special cases, such as Palestine, may necessitate prevailing one of the other objective function over the monetary benefits. For instance, the unemployment rate in Palestine was 15% in the 1990s (Butterfield et al 2000) and rose to 27% in the last few years (PCBS 2015). Furthermore, the agricultural production has to satisfy the increasing demand for food due to the population growth Palestine lately experiences. In order to show the effect of the weighting ratios, the ranks of the first five proposed policies are depicted in **Table (8).**

Table (8): The best five proposed policies obtained by the utility theory using different weights.

f	Weights for each objective function		
NetBen	50%	25%	25%
PRODUCT	25%	50%	25%
LABOR	25%	25%	50%
Policy rank			
1	P33	P35	P1
2	P32	P36	P2
3	P34	P34	P3
4	P35	P33	P4
5	P31	P32	P5

The problems of the utility theory involve the determination of the fulfillment of goals. The system can also be in disequilibrium and includes dependent goals which complicate the determination of the single weights (see Bell et al 1988; Keeney and Raiffa 1993). In the utility theory a less successful fulfillment of a goal can be compensated by better fulfillment of another.

Benefit Cost Analysis:

Benefit cost analysis is a tool to evaluate how attractive markets are for possible governmental intervention (Kahraman 2008). This is to compare this governmental intervention to the status quo option. Benefit cost analysis is to assess the value for money of large projects at different levels (Kahraman 2008). Such projects usually include costs and benefits that cannot necessarily be expressed in monetary terms such as environmental degradation, social responsibility, sustainability, etc. (Kahraman 2008) .

In the utility theory, the achievements of the goals were expressed in non-dimensional units. Using the benefit cost analysis all the effects of a project, which cannot be expressed in monetary values, are expressed by their benefit. The net benefit should be greater than one if the revenue of a proposed policy is greater than the cost and vice versa. Thus, the revenue should be used in this analysis not the net benefit. This benefit cost analysis can by summarized in **Eqn. (14):**

$$\text{Benefit cost ratio} = \text{B/C} = \frac{\text{Revenue}}{\text{Cost}} \qquad \textbf{Eqn. (14)}$$

The benefit cost ratio for each alternative has been evaluated and the results are shown in **Table (9).** Afterward, the proposed policies are ranked based on the benefit cost ratio.

Spearman Rank Correlation Coefficient:

The results obtained from the benefit cost analysis are compared to those obtained from the utility theory of 50% weighted net benefit objective function. Both results are really close to each other. This verifies what is mentioned in the economic theory that the benefit from benefit cost analysis can be determined with the utility theory.

Spearman rank correlation coefficient (R) is useful to determine the measure of association between ranks obtained by different methods (Raju and Kumar 1999). If Ua and Va denote the ranks achieved by two different methods for the same alternative a, then the coefficient R is defined as shown in Eqn. (15) (see Raju and Kumar 1999):

$$R = 1 - \frac{6\times\sum_{a=1}^{A} D_a^2}{A(A^2-1)} \qquad \textbf{Eqn. (15)}$$

in which a is the number of alternatives (a = 1, 2, ..., A); A is the total number of alternatives; and D_a is the difference between ranks (U_a - V_a).

Table (9): The benefit cost ratios of the 36 proposed policies

Policy	Revenue	Water cost	Prod. Cost	B / C
P1	1.2E+06	9.6E+04	3.5E+05	2.686
P2	1.2E+06	9.6E+04	3.5E+05	2.696

P3	1.2E+06	9.6E+04	3.5E+05	2.706
P4	1.2E+06	9.6E+04	3.5E+05	2.716
P5	1.2E+06	9.6E+04	3.5E+05	2.725
P6	1.2E+06	9.6E+04	3.5E+05	2.735
P7	1.2E+06	9.6E+04	3.6E+05	2.745
P8	1.2E+06	9.6E+04	3.6E+05	2.755
P9	1.3E+06	9.6E+04	3.6E+05	2.764
P10	1.3E+06	9.6E+04	3.6E+05	2.774
P11	1.3E+06	9.6E+04	3.6E+05	2.783
P12	1.3E+06	9.6E+04	3.6E+05	2.793
P13	1.3E+06	9.6E+04	3.6E+05	2.802
P14	1.3E+06	9.6E+04	3.6E+05	2.812
P15	1.3E+06	9.6E+04	3.6E+05	2.821
P16	1.3E+06	9.6E+04	3.6E+05	2.831
P17	1.3E+06	9.6E+04	3.6E+05	2.840
P18	1.3E+06	9.6E+04	3.6E+05	2.849
P19	1.3E+06	9.6E+04	3.7E+05	2.859
P20	1.3E+06	9.6E+04	3.7E+05	2.868
P21	1.3E+06	9.6E+04	3.7E+05	2.877
P22	1.3E+06	9.6E+04	3.7E+05	2.886
P23	1.3E+06	9.6E+04	3.7E+05	2.895
P24	1.4E+06	9.6E+04	3.7E+05	2.905
P25	1.4E+06	9.6E+04	3.7E+05	2.914
P26	1.4E+06	9.6E+04	3.7E+05	2.923
P27	1.4E+06	9.6E+04	3.7E+05	2.932
P28	1.4E+06	9.6E+04	3.7E+05	2.941
P29	1.4E+06	9.6E+04	3.7E+05	2.950
P30	1.4E+06	9.6E+04	3.7E+05	2.959
P31	1.4E+06	9.6E+04	3.8E+05	2.968
P32	1.4E+06	9.6E+04	3.8E+05	2.977
P33	1.4E+06	9.6E+04	3.8E+05	2.979
P34	1.4E+06	9.6E+04	3.8E+05	2.971
P35	1.4E+06	9.6E+04	3.8E+05	2.964
P36	1.4E+06	9.6E+04	3.8E+05	2.959

In order to better interpret the results, three cases are illustrated here: 1) R = 1 represents perfect association between the ranks, 2) R = 0 represents no association between the ranks, and 3) R = -1 represents perfect disagreement between the ranks (Raju and Kumar 1999).

The value of R always lies between -1 and +1. Spearman rank correlation coefficient (R) is computed to assess the degree of correlation between the utility theory and the benefit cost theory methods. The squared difference between Ua and Va (D_a^2) equals 104. With the number of alternatives (A = 36 in this case), R value between the utility theory and the benefit cost theory is 0.9866 indicating nearly perfect association between the two methods.

Cluster Analysis :

The number of reduced non-dominated alternatives obtained from multiple-objective optimization (36 in this case) is still considerably large. The method of "cluster analysis" can be used to reduce the number of alternatives to a more manageable subset (Morse 1980). There are several software that are developed to perform the cluster analysis. Cluster analysis using these software offers several advantages over a manual grouping process (e.g., Jain and Dubes 1988). However, the software used for clustering is unavailable; therefore, it is done using simple calculations in a MS Excel spreadsheet .

Cluster analysis partitions non-dominated alternative set N into K clusters (groups) of relatively homogeneous alternatives. The K-means clustering algorithm (Hartigan 1975; Jain and Dubes 1988) is used to minimize within-cluster sums of squares of differences based on the initial partitions to obtain final partitions. In this method, alternatives are grouped so that each alternative is assigned to one of the fixed number of groups K. The sum of the squared differences of each criterion from its assigned cluster mean (of the same group) is used as the criterion for the assignment (Raju and Kumar 1999). The total square error value for cluster group K, EK is given by Eqn. (16) (see Raju and Kumar 1999):

$$E_K = \sum_{K=1}^{12} e_K^2 \qquad \textbf{Eqn. (16)}$$

in which eK is the error value for each cluster group K. The K-means clustering, with more than one value of K, is performed and the value of K which best fits the data is used. Burn (1989) proposed F-statistic value as a benchmark to select the optimal number of clusters. This value of F is a measure of the reduction in variance from K to K+1 cluster. Typically, the value of F greater than 10 at P = 0.05 justifies a transition from K to K+1 cluster (Burn 1989). The F- statistic can be defined by Eqn. (17) as (see Burn 1989):

$$F = [E_K/E_{K+1}\text{-}1](N - K + 1) \qquad \textbf{Eqn. (17)}$$

in which EK+1 is the total square error value for all cluster groups (K+1) and N is the number of non-dominated alternatives. Figure 8 presents square error and F-statistic values for clustering having partitions varying from 1 to 8. It is observed that the values of square error and F-statistic are decreasing with the increase in number of clusters. The optimum number of cluster groups is taken as three corresponding to the F-statistic value of 10.

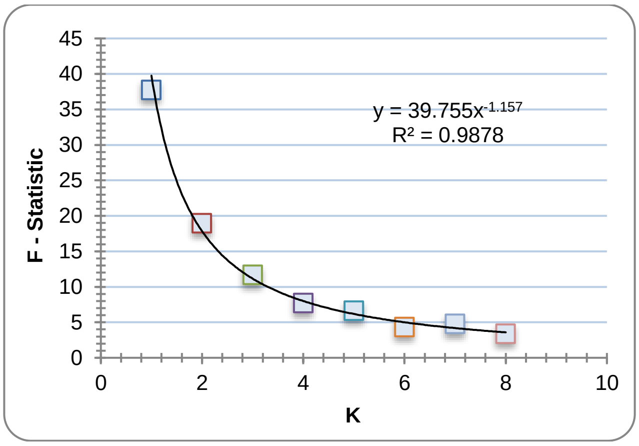

Figure (8): The values of square error and F-statistic for several numbers of clusters.

After fixing the optimal number of clusters to three, the representative policy for each cluster is determined as shown in Table 10. For this purpose, the square error values between group mean and the proposed policy values for each criterion in that group are calculated. The summation of these square error values for all criteria gives the total square error value corresponding to each proposed policy in that group. The policy that gives the minimum total square error value is chosen as the representative policy for that particular group.

The policies P06, P18, and P30 of Table 10 having the minimum total square error values of 8,385,030.84, 8,392,367.92, and 6,423,072.87 are found to be the representative ones of the three cluster groups (see Table 10). The above groups are denoted as G1, G2, and G3 hereafter. Alternative policies versus criteria array are presented in **Table (11).**

Multiple Criteria Decision Making:

Multiple criteria decisions making (MCDM) is the study of methods and procedures by which challenges of multiple conflicting criteria can be properly tackled (Kou et al 2011). Two MCDM methods, namely the weighted goal programming (WGP) and the step method (STEM), are employed in the evaluation. Romero and Rehman (2003) can be used as a reference illustrating approaches to use the MCDM's and their application, specifically, for agricultural purposes.

Table (10): The proposed policy values and the corresponding square error values.

Policy	Production	Labor	Net benefit	e	
No.	*Ton*	*Day*	*$*		
P1	2573	16083	7.53E+05	1.02E+09	
P2	2597	16039	7.59E+05	6.80E+08	
P3	2621	15995	7.64E+05	4.11E+08	
P4	2645	15951	7.70E+05	2.10E+08	
P5	2669	15907	7.76E+05	7.55E+07	
P6	2693	15863	7.82E+05	8.39E+06	Min
P7	2717	15819	7.87E+05	8.40E+06	
P8	2741	15775	7.93E+05	7.56E+07	
P9	2765	15731	7.99E+05	2.10E+08	
P10	2789	15687	8.05E+05	4.11E+08	
P11	2813	15643	8.11E+05	6.80E+08	
P12	2837	15599	8.16E+05	1.02E+09	
Average	**2705**	**15841**	**7.85E+05**	**4.80E+09**	
P13	2861	15555	8.22E+05	1.02E+09	
P14	2885	15511	8.28E+05	6.80E+08	
P15	2909	15467	8.34E+05	4.11E+08	
P16	2933	15423	8.40E+05	2.10E+08	
P17	2957	15379	8.45E+05	7.55E+07	
P18	2981	15335	8.51E+05	8.39E+06	Min
P19	3005	15291	8.57E+05	8.39E+06	
P20	3029	15247	8.63E+05	7.55E+07	
P21	3053	15203	8.69E+05	2.10E+08	
P22	3077	15159	8.74E+05	4.11E+08	
P23	3101	15115	8.80E+05	6.80E+08	

P24	3125	15071	8.86E+05	1.02E+09	
Average	**2993**	**15313**	**8.54E+05**	**4.80E+09**	
P25	3149	15027	8.92E+05	6.99E+08	
P26	3173	14983	8.98E+05	4.26E+08	
P27	3197	14939	9.03E+05	2.20E+08	
P28	3221	14895	9.09E+05	8.20E+07	
P29	3245	14851	9.15E+05	1.06E+07	
P30	3269	14807	9.21E+05	6.42E+06	Min
P31	3293	14763	9.27E+05	6.94E+07	
P32	3317	14719	9.32E+05	1.99E+08	
P33	3341	14675	9.35E+05	2.75E+08	
P34	3365	14631	9.32E+05	1.84E+08	
P35	3389	14587	9.29E+05	1.11E+08	
P36	3405	14533	9.27E+05	7.30E+07	
Average	**3280**	**14784**	**9.18E+05**	**2.36E+09**	

Table (11): The alternative policies versus criteria array.

Policy	Production	Labor	Net benefit
No.	***Ton***	***Day***	***$***
P6	2693	15863	781700.5
P18	2981	15335	851224.6
P30	3269	14807	920748.7

The Weighted Goal Programming Method:

This method of goal programming targets all the goals simultaneously in a composite objective function (Romero and Rehman 2003). In this method, the sum of all deviations among the goals from their aspiration levels is minimized (Romero and Rehman 2003). From the payoff matrix of the model in Table 5, the target values for the three objective functions can be obtained. The deviations are weighted according to the relative importance attached to each goal by the DM. The variables in the objective function must represent percentage deviations from the targets rather than absolute deviations because of the widely different units of measurements used for the goals, i.e., the objective functions. Thus, Romero and Rehman (2003) showed that the WGP formulation is described as shown in Eqn. (18):

$$\text{Minimize } z = w_1 \frac{n_1}{978{,}723}\frac{100}{1} + w_2 \frac{n_2}{3{,}405}\frac{100}{1} + w_3 \frac{n_3}{16{,}083}\frac{100}{1} \qquad \text{Eqn. (18)}$$

subject to

$$Max\ NetBet: \sum_{i=1}^{5} R_i A_i - P_{GW}\sum_{i=1}^{5}(WR_i)A_i - \sum_{i=1}^{5}(PC_i)A_i + n_1 - p_1 = 978{,}723$$

$$Max\ PRODUCT: \sum_{i=1}^{5} Y_i A_i + n_2 - p_2 = 3{,}405$$

$$Max\ \text{LABOR}: \sum_{i=1}^{5} L_i A_i + n_3 - p_3 = 16{,}083$$

(in addition to the original constraints of the model) in which w_i represents the weight attached to the deviational variables n_i and p_i. Different solutions can be obtained by attaching different values to these parameters. The results are summarized in **Table (12).**

Assume now that the DM assigns a greater importance to increasing the labor employment than the other objective functions. In this case, a higher weight should be given to the deviational variables, namely n3 and p_3. The linear programming solution does not change if the weight attached to n_3 is increased up to five times the values associated with the other deviational variables. Yet beyond that, the optimal solution changes and satisfies full achievement to the LABOR goal. The code used to model the WGP method is attached in Appendix C.

Table (12): The results of the weighted goal programming method.

RUN	Weight for each objective function			GOALS			f
	w1	*w2*	*w3*	*NETBEN*	*PRODUCT*	*LABOR*	*MIN Z*
1	1	0	0	978723	2992	14533	3.92E-05
2	0	1	0	926544	3405	14725	0
3	0	0	1	752699	2573	16083	0
4	1	1	0	926752	3405	14726	5.31
5	1	0	1	978723	2992	14533	9.64
6	0	1	1	926626	3405	14727	8.43
7	2.3	1	0	978723	2992	14533	12.13
8	1	0	2.2	978723	2992	14533	21.21
9	0	1	2.8	926626	3405	14727	23.61
10	1	1	1	926752	3405	14726	13.75
11	1	1	3	926626	3405	14727	30.62
12	2.6	1	1	978723	2992	14533	21.77
13	1	1	5.1	752716	2573	16083	47.52

The Weighted Goal Programming Method:

Benayoun et al (1971) had proposed an interactive MCDM approach called the step method (STEM). It is perhaps the oldest such method and has been also one of the most widely used. The interactive MCDM approach implies a progressive evolution and definition of the DM preferences through an interaction between the DM and the results generated from various runs of the model as shown in Figure 9. The interaction begins with an initial set introduced to the DM for a feedback to update, and this process is repeated back and forth to approach a desirable decision based on the DM preferences (Romero and Rehman 2003). The general purpose of this approach is to obtain a local approximation relevant to a specific situation of the DM utility function or the point of maximum utility through an interaction between the DM and the model (Romero and Rehman 2003).

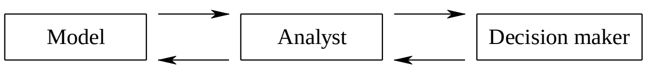

Figure (9): The interactive decision-making process (Romero and Rehman 2003).

The STEM method proceeds in two phases: (1) a calculation phase and (2) a decision phase. The interaction between the DM and the model takes place in the second phase only in the form of a third phase of communication. The first step in the calculation phase is to generate the payoff matrix (**see Table 5)** in order to obtain the ideal (f_{max}) and the anti-ideal (f_{min}) values of each of the objective functions included in the model. Thus, Romero and Rehman (2003) showed that the STEM formulation is as follows in **Eqn. (19):**

$$Min\ d \qquad \textbf{Eqn. (19)}$$

subject to

$$W_j[f_{max} - f(A_i)] \leq d$$

The normalizing weights W_j in the STEM method are defined as

$$W_j = \frac{v_j}{\sum_{j=1}^{3} v_j}$$

in which

$$v_j = \left[\frac{f_{max} - f_{min}}{f_{max}}\right]\left(\frac{1}{\sqrt{\sum_{i=1}^{5} c_{ij}}}\right)$$

In the above expression c_{ij} represent the coefficients of the j_{th} objective. The weights Wi's are just normalizing weights and do not represent the preferences of the DM. The first term of the v_j equation gives more weight to the objective function with the largest difference between the minimum and maximum values. The second term; however, is to normalize the objectives according to the Euclidean distance (see Romero and Rehman 2003).

The decision phase starts by presenting the efficient solution in the objective space defined by the first constraint to the DM. if the DM accepts the optimum solution after comparing it with the ideal vector, then the process ends; if it is not acceptable, then the DM must indicate which attribute(s) of the solution could be worsened or degraded so that the others could be improved. The DM must also indicate the maximum degradation possible before a satisfactory level of an attribute becomes unsatisfactory. This information imposes the following additional restraints on the problem (**see Eqn. 20**) before a new feasible set is generated (see Romero and Rehman 2003):

$$f_k(A_i) \geq f_k^1 - \Delta f_k \qquad \textbf{Eqn. (20)}$$
$$f_j(A_i) \geq f_j^1 \qquad j = 1, 2, ..., k\text{-}1, k + 1, ..., q$$

in which f_k is the satisfactory objective, Δf_k is the maximum degradation allowed in its achievement level, and the vector $[f_j, ..., f_k]$ is the solution in the objective space. For the next iteration obviously $v_k = 0$, $W_k = 0$ and therefore the other normalizing weights have to be recalculated. With the new W_j weights and the new feasible set as augmented by the additional restraints from Eqn. (20), a new efficient solution is obtained, which is once again evaluated by the DM. This iterative process goes on until the DM is satisfied with a given solution (see Romero and Rehman 2003). Benayoun et al (1971) claimed that their method converges to a solution in less than q iteration, q being the number of objectives; otherwise, the STEM method is not suitable for modeling the preference of the DM.

The procedure above is followed to develop the STEM model on LINGO. The model input data and the results are summarized in Table 13. In addition, the code used to model the STEM method is attached in Appendix D.

Table (13): The step method input data and the results before consulting the DM.

f(A)	f_{max}	f_{min}	A_2	A_3	A_4	ν_j	W_j	Results
NetBen	978723	752712	1170.04	1144.9	1006.88	1.20E-04	0.0030	941423
PRODUCT	3405	2573	4	3.5	3.7	3.77E-02	0.9278	3288
LABOR	16083	14533	25	17	16	2.82E-03	0.0693	14671

Therefore, the optimal solution for this model is $941,423, 3,288 tons, and 14,671 labor days for the net benefit, the agricultural production, and the labor employment objectives, respectively. These results are close to those of the proposed policy (P30) obtained by the cluster analysis. Now, the decision phase starts and the DM is consulted. If the DM accepts this optimum solution, then the task will be done. If the DM decides that it is acceptable to get a net benefit of at least $900,000 in order to gain greater agricultural production and provide more labor days, the input data should be changed based on the new set of restraints and the results are shown in Table 14. The code used to model this revised STEM method is attached in Appendix E.

Table (14): The step method input data and the results after consulting the DM.

f(A)	f_{max}	f_{min}	A_2	A_3	A_4	ν_j	W_j	Results
NetBen	978723	752712	1170.04	1144.9	1006.88	0	0	907741
PRODUCT	3405	2573	4	3.5	3.7	3.77E-02	0.9305	3315
LABOR	16083	14533	25	17	16	2.82E-03	0.0695	14874

It is observed that the net benefit decreases by $33,682 in order to gain additional 26 tons of agricultural production and provide additional 203 labor days. If this optimum solution is satisfactory to the DM, then the task will be done. Otherwise, this step is repeated to the satisfactory level of achievement of objectives and so on.

CONCLUSIONS:

Farmers need assistance from agronomists and decision makers to cultivate the proper products and utilize their vulnerable water and land resources. In this study, the best selection of agricultural crops is addressed in the context of multiple objective functions. The study deals with three conflicting objective functions: net benefit, agricultural production, and labor employment. The three objective functions are carefully selected so that decision makers can get an accurate assessment of the existing agricultural system. Any successful decision should not depend only on financial feasibility assessment, but also on political, socio-economic, technological, and environmental considerations. It is important to keep in mind that Palestinians have neither control on local business markets nor access to foreign business markets. This exacerbates the challenge on farmers to marketing their agricultural products .

Four-stage procedure is adopted in this study combining multiple-objective optimization, simple valuation methods, cluster analysis, and multiple criteria decisions making (MCDM) methods. Pareto optimal curves are used to evaluate the marginal prices of both land area and Labor Day. The utility theory and benefit cost theory are applied to rank the non-dominant alternatives. The method of "cluster analysis" is a powerful tool to reduce the number of non-dominant alternatives to a manageable subset. Two MCDM methods, namely the weighted goal programming and step methods, are employed in the evaluation. A comparison between the two MCDM methods including the pros and cons of each is basically made. The good thing about MCDM methods that they function interactively to help the model respond to the preferences of the decision maker .

The above methodology is applied to the case study of Qalqilya District in which irrigated agriculture prevails. The results show that Pareto optimal is a powerful tool to determine the marginal price of non-monetary commodities. The cluster analysis reduces the large number of non-dominant alternatives to merely a few proposed policies. It is worth to mention that one of these three proposed policies is almost similar to that obtained by one of the MCDM methods that uses totally different and independent procedure to get the optimal solution.

Based on the analysis of the results of a real-world irrigation planning problem at Qalqilya District, the following conclusions are drawn:

- Palestinian agriculture is constrained by available land and water, as well as access to markets.
- Water shortage is the limiting parameter that constraints the development of agriculture in Qalqilya District.
- Pareto optimal is a powerful tool to determine the marginal price of non-monetary commodities.
- Utility theory and benefit cost theory both can be used to rank non-dominated alternatives .
- Spearman rank correlation coefficient is found to be very useful to assess the correlation between two ranking methods. Spearman rank correlation coefficient (value between utility theory and benefit cost theory is 0.9866 indicating nearly perfect association between the two methods .
- Cluster analysis is found to be an effective tool to reduce the large number of the non-dominated alternatives to a manageable set (from 36 to 3) .
- It is found that the annual net benefits, agricultural production, and labor employment on average for the cultivated area are $941,423, 3,288 tons, and 14,671 days, respectively, in the best compromise plan.

In the light of this paper, the author recommends the following:

- The actual demand curve for each vegetable is to be used, so that the actual market price will not be constant .
- The scale of this study must be enlarged to cover trees, vegetables, and crops grown in the study area.
- The interdisciplinary studies that combine economic theories into engineering optimization algorithms to developing the agricultural sector should have been greatly encouraged, particularly after the onset of the novel coronavirus pandemic .
- Recent agricultural statistics are to be used so that information and data in this study can be updated.

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APPENDICES:

Appendix A:

The model code of the individual optimization of NetBen objective function

Model:

```
MAX = (795*A1 + 1864*A2 + 1692*A3 + 1521*A4 + 565*A5) - 0.19*1000*(0.9*A1 + 0.784*A2 +
    0.59*A3 + 0.548*A4 + 0.750*A5) - (395*A1 + 545*A2 + 435*A3 + 410*A4 + 435*A5);
NetBen = (795*A1 + 1864*A2 + 1692*A3 + 1521*A4 + 565*A5) - 0.19*1000*(0.9*A1 + 0.784*A2 +
    0.59*A3 + 0.548*A4 + 0.750*A5) - (395*A1 + 545*A2 + 435*A3 + 410*A4 + 435*A5);
PRODUCT = 1.5*A1 + 4*A2 + 3.5*A3 + 3.7*A4 + 1.8*A5;
LABOR = 18*A1 + 25*A2 + 17*A3 + 16*A4 + 17*A5;
A1 + A2 + A3 + A4 + A5 <= 1000;
AREA = A1 + A2 + A3 + A4 + A5;
1000*(0.9*A1 + 0.784*A2 + 0.59*A3 + 0.548*A4 + 0.750*A5) <= 504364;
WATER = 1000*(0.9*A1 + 0.784*A2 + 0.59*A3 + 0.548*A4 + 0.750*A5);
END
```

Appendix B:

The model code of the NetBen vs. PRODUCT Pareto curve

Model:

```
MAX = (795*A1 + 1864*A2 + 1692*A3 + 1521*A4 + 565*A5) - 0.19*1000*(0.9*A1 + 0.784*A2 +
    0.59*A3 + 0.548*A4 + 0.750*A5) - (395*A1 + 545*A2 + 435*A3 + 410*A4 + 435*A5);
NetBen = (795*A1 + 1864*A2 + 1692*A3 + 1521*A4 + 565*A5) - 0.19*1000*(0.9*A1 + 0.784*A2 +
    0.59*A3 + 0.548*A4 + 0.750*A5) - (395*A1 + 545*A2 + 435*A3 + 410*A4 + 435*A5);
PRODUCT = 1.5*A1 + 4*A2 + 3.5*A3 + 3.7*A4 + 1.8*A5;
PRODUCT >= 3360;
LABOR = 18*A1 + 25*A2 + 17*A3 + 16*A4 + 17*A5;
LABOR = 14629.686;
A1 + A2 + A3 + A4 + A5 <= 2083;
AREA = A1 + A2 + A3 + A4 + A5;
1000*(0.9*A1 + 0.784*A2 + 0.59*A3 + 0.548*A4 + 0.750*A5) <= 504364;
WATER = 1000*(0.9*A1 + 0.784*A2 + 0.548*A3 + 0.548*A4 + 0.750*A5);
A1 >= 0;
A2 >= 0;
A3 >= 0;
A4 >= 0;
A5 >= 0;
END
```

Appendix C:

The model code of the WGP

Model:

```
MIN = (W1*N1*100/978723) + (W2*N2*100/3405) + (W3*N3*100/16083);
W1 = 1;
W2 = 1;
W3 = 1;
(795*A1 + 1864*A2 + 1692*A3 + 1521*A4 + 565*A5) - 0.19*1000*(0.9*A1 + 0.784*A2 + 0.59*A3 +
    0.548*A4 + 0.750*A5) - (395*A1 + 545*A2 + 435*A3 + 410*A4 + 435*A5) + N1 - P1 = 978723;
1.5*A1 + 4*A2 + 3.5*A3 + 3.7*A4 + 1.8*A5 + N2 - P2 = 3405;
18*A1 + 25*A2 + 17*A3 + 16*A4 + 17*A5 + N3 - P3 = 16083;
NetBen = (795*A1 + 1864*A2 + 1692*A3 + 1521*A4 + 565*A5) - 0.19*1000*(0.9*A1 + 0.784*A2 +
    0.59*A3 + 0.548*A4 + 0.750*A5) - (395*A1 + 545*A2 + 435*A3 + 410*A4 + 435*A5);
PRODUCT = 1.5*A1 + 4*A2 + 3.5*A3 + 3.7*A4 + 1.8*A5;
LABOR = 18*A1 + 25*A2 + 17*A3 + 16*A4 + 17*A5;
A1 + A2 + A3 + A4 + A5 <= 1000;
AREA = A1 + A2 + A3 + A4 + A5;
1000*(0.9*A1 + 0.784*A2 + 0.59*A3 + 0.548*A4 + 0.750*A5) <= 504364;
WATER = 1000*(0.9*A1 + 0.784*A2 + 0.548*A3 + 0.548*A4 + 0.750*A5);
END
```

Appendix D:

The model code of the STEM method

Model:

```
MIN = D;
0.0029*(978723 - 1170.04*A2 - 1144.9*A3 - 1006.88*A4) <= D;
0.9278*(3405 - 4*A2 - 3.5*A3 - 3.7*A4) <= D;
0.0693*(16083 - 25*A2 - 17*A3 - 16*A4) <= D;
NetBen = 1170.04*A2 + 1144.9*A3 + 1006.88*A4;
PRODUCT = 4*A2 + 3.5*A3 + 3.7*A4;
LABOR = 25*A2 + 17*A3 + 16*A4;
A2 + A3 + A4 <= 1000;
AREA = A2 + A3 + A4;
1000*(0.784*A2 + 0.59*A3 + 0.548*A4) <= 504364;
WATER = 1000*(0.784*A2 + 0.59*A3 + 0.548*A4);
END
```

Appendix E:

The model code of the revised STEM method (after decision making)

Model:

```
MAX = (1864*A2 + 1692*A3 + 1521*A4) - 0.19*1000*(0.784*A2 + 0.59*A3 + 0.548*A4) - (545*A2 +
    435*A3 + 410*A4);
NetBen (1864*A2 + 1692*A3 + 1521*A4) - 0.19*1000*(0.784*A2 + 0.59*A3 + 0.548*A4) - (545*A2 +
    435*A3 + 410*A4);
PRODUCT = 4*A2 + 3.5*A3 + 3.7*A4;
LABOR = 25*A2 + 17*A3 + 16*A4;
A2 + A3 + A4 <= 2083;
AREA = A2 + A3 + A4;
1000*(0.784*A2 + 0.59*A3 + 0.548*A4) <= 504364;
WATER = 1000*(0.784*A2 + 0.59*A3 + 0.548*A4);
END
```