Vehicle Routing Solution Reduces Transportation Costs for Organic Farmers Serving the Domestic Market in Turkey

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Abstract

In this paper, our goal is to overcome one of the barriers impeding the development of the domestic organic market, specifically to reduce the transportation costs incurred by the farmers shipping organic produce to the largest organic market in Istanbul. The sample data includes 62 fresh produce suppliers. To design an efficient transportation system, we propose a vehicle routing model. We formulate the problem using GAMS modelling system and solve it with an integer programming solver in a reasonable amount of time. The results, reducing unit transportation costs by almost 50%, show the economic impact of a collective transportation arrangement.

Keywords: Organic Agriculture, Supply Chain Management, Transportation Costs, Vehicle Routing, Food Logistics, Organic Market

1. Introduction

It is now a known fact that organic agriculture is a remedy for a long list of contemporary socio-economic and environmental problems. The favourable effects of organic agriculture range from reducing carbon emissions; increasing yields in low-input areas; conserving bio-diversity and nature resources on the farm and in the surrounding area; increasing income, reducing costs and providing employment for farm families to producing safe and varied food for the society, (Badgley et al., 2007; Demiryürek, Stopes, & Güzel, 2008; Gündoğmuş, 2006; Morison, Hine, & Pretty, 2005; Neale, 2008). Organic agriculture also emphasizes the sustainability of farm families and rural communities, regional development and culturally rooted food production systems, (IFOAM, 2008). Such features are particularly beneficial to smallholders who seek employment outside farming when left unprotected in the face of market forces, (Keyder & Yenal, 2011). Several scientists are studying alternative food production and consumption policies, (Altieri & Rosset, 1996; Cockshott & Cottrell, 1993), incorporating more organic, regional and traditional foods with more legumes, fruits and vegetables for a healthier and environmentally friendlier diet, (Fukuoka, 1978; Saxe, Larsen, & Mogensen, 2013; Bere & Brug, 2008), seriously considering the viability of feeding an entire population of a country with organic foods, (Demir, 2007). Turkey makes up an interesting example, its climate and biodiversity are very suitable for organic agriculture (Bakırcı, 2005; Demiryürek, 2004; Kenanoğlu & Karahan, 2002) and the country's production capability is expanding. Figures reported by the Ministry of Food, Agriculture and Livestock of Turkey show that the land allocated to organic agriculture quadrupled in the period 2004-2011 and total production quantity increased by sevenfold from 379 thousand tons to about 3 million tons, in the same period1. However, more than 99% of the production is exported2 and the growth of sales in the domestic organic market is by no means as promising.

[1]http://www.tarim.gov.tr/images/Files/sag3fixmenu/bilgiler_veriler/BUGEM.pdf. Accessed 6 November 2012.

[2]2009 data compiled by FiBL and IFOAM (http://www.organic-world.net) reveal that the proportion of Turkey's organic agricultural land to the world total is about 1% whereas the proportion of domestic sales of organic products in Turkey to the world total is less than 0.01%.

Several reasons can be listed to explain this underdeveloped state: limited sales channels and unavailability of organic products, high price premiums, low purchasing power of majority of the citizens, very high fuel prices, costs of conversion, lack of subsidies, lack of government support and low consumer awareness, (Demiryürek, 2004; Kenanoğlu & Karahan, 2002; Özbilge, 2007). To develop organic agriculture in a country properly, the domestic sector needs to be developed, (Demiryürek, 2004; Joshi & Hioki, 2012; Kenanoğlu & Karahan, 2002; Özbilge, 2007). An attempt in this direction was made by civil society led by Buğday Association for Supporting Ecological Living and in 2006, an organic bazaar, an open-air marketplace where only certified organic products are traded, has been established in İstanbul, the largest city of Turkey. This first organic bazaar formed a food supply chain with Buğday, a non-governmental and not-for-profit organization (NGO), as the chain captain bringing together stakeholders of the organic sector, (Demir, 2013). This development indeed caused a mobilization of the domestic sector by providing the very much needed sales channel for organic farmers. The increase in the number of farmers supplying fresh produce and the amount traded in the period between October 2006 and October 2009 was followed by the launch of the second organic bazaar in December 2009. The first organic bazaar of İstanbul has set an example and inspired the opening of other organic marketplaces. The number of such marketplaces of Turkey reached a total of 10 today. Besides being a remedy to problems of organic farmers, the launch of these organic marketplaces had a positive effect on the domestic market by providing a meeting place for farmers and consumers and an arena for exchange of ideas and discussions. The domestic market started to expand with stores selling organic produce (physically or on the Internet), restaurants providing organic menus and supermarkets allocating space for organic foods. The organic bazaar formed an alternative food network and displayed some of the critical activities of supply chains such as integrated behaviour; mutually sharing information; mutually sharing risks and rewards; cooperation; the same goal and the same focus on serving customers, (Demir, 2013).

The law dictates that municipalities administer all such marketplaces. Municipalities in return choose to collaborate with an NGO. In the case of the first organic bazaar of İstanbul, Buğday, controls the organic certificates, communicates with farmers, producers, packagers, processors and middlemen and handles governance problems. A complaint frequently raised by farmers shipping produce to the organic bazaar is about the high level of transportation costs. NGO officials also confirm that these high transportation costs elevate the price premium paid for organic produce and is harming the organic sector as a whole.

The market for conventional fresh produce operates through wholesale markets in cities; where supermarkets, stores and merchants trading daily on neighborhood marketplaces make their purchases. This leads to low transportation costs in the range of 0.10-0.15 Lira (L)3 per kilogram in the conventional market. But for reasons of safety, reliability, traceability and contamination, organic products cannot be shipped with trucks carrying conventional produce. This restriction leaves small farmers4 with only two alternatives: either to operate their own transportation means or to use cargo companies. The majority of organic produce suppliers of the organic bazaar are smallholders who produce, transport and sell in low tonnages and who cannot afford to operate their own vehicle. These farmers have no other choice than using cargo companies and paying high unit transportation costs reaching six-fold of that incurred by conventional farmers, causing an increase in unit sale prices of organic food products. A farmer with only 16 acres of land reported incurring a unit transportation cost of 0.60 L per kilogram by the cargo company. At a market where average prices5 of produce are around 3-5 L per kilogram, transportation costs account for about 12-20% of the sales revenue for small scale farmers. Therefore, transportation is a serious problem for Istanbul's organic bazaar and an efficient transportation scheme is needed.

In this paper, we propose a vehicle routing formulation to reduce unit transportation costs incurred by the farmers supplying organic produce to the organic bazaar in İstanbul. The contribution of this work lies in finding a workable solution to a real-life problem of organic farmers by using optimization techniques. With this application, we help to close the gap between existing knowledge and expertise in mathematical modelling and their real world applications. The proposed solution is also an attempt towards the integration of processes, a critical activity for successful supply chain management, (Mentzer et al., 2001).

[3] Lira is the Turkish currency and 1 Lira is equivalent to 0.55 USD and 0.43 Euro as of May 2013.

[4] This is not a big problem for large farmers; a participating farmer possessing more than 1000 acres of farmland, who is sufficiently well off that he uses his own vehicles for transportation, reported incurring a unit transportation cost of 0.25 L per kilogram of produce. It should be noted that he has no idle running costs since he can employ his truck all week long.

[5] The average prices and unit transportation costs are based on 2009 figures.

The model, presented in Section 3, and its solution in Section 4, bring considerable savings in unit transportation costs reducing the total distance travelled by fresh organic produce and contributing to the reduction of fossil fuel consumption and carbon emissions as well. By encouraging the consumption of local and organic food and reducing costs incurred by the small scale farmers in particular, our model has positive environmental and socio-economic impacts.

The paper is organized as follows: vehicle routing problems are discussed in Section 2 with a brief literature review on mathematical models and route optimization for organic agriculture. In Section 3, we provide the formulation of the problem and explain how we apply the formulation to the problem on hand. We also display the data used to run one instance of the model; these are supply quantities provided by the farmers and collected by Buğday, the overseer NGO. In Section 4, we present the solution and propose a system that can collectively be used by the suppliers of the organic bazaar to reduce their unit transportation costs by 40-50% and finally in Section 5, we conclude the paper.

2. Previous Work on Route Optimization of Organic Goods

There are several studies using mathematical models to solve problems of agriculture, (Moss, 2002; Williams, 1999). In organic agriculture, mostly farm level studies are conducted using goal programming, dynamic linear programming or data envelopment analysis, (Acs, Berentsen, & Huirne, 2007; Kerselaers et al., 2007; Pacini et al., 2004; Annetts & Audsley, 2002; Oude Lansink, Pietola, & Bäckman, 2002). A country level preliminary linear programming formulation to satisfy Turkey's food needs via organic products can be found in (Demir, 2007).

The problem faced by the producers of the organic market has a combinatorial nature, that of vehicle routing. A generalization of the traveling salesmen problem, the vehicle routing problem (VRP) has first been proposed by Dantzig and Ramser (1959) as the truck dispatching problem. Clarke and Wright (1964) proposed the first heuristic, Christofides, Mingozzi, and Toth (1981b) used state space relaxation to solve the capacitated VRP, Christofides et al. (1981a) used branch-and-bound to solve VRPs with up to 25 vertices and Magnanti (1981) pointed out the interplay between formulations and algorithms and the combined use of exact algorithms and heuristics as a future direction for the field. Exact solution methods were available however the size of problems that can be solved remained limited to about 50 customers. The advances in computing technology in connection with heuristics enabled the solution of larger problems. In the last decade, researchers working on improving exact methods, employing branch and cut, branch-cut-price or set partitioning, reported very good computational results solving problems with up to 120 customers, (Baldacci, Mingozzi, & Roberti, 2011; Fukasawa et al., 2006; Lysgaard, Letchford, & Eglese, 2004). With great practical relevance and difficulty of solution, VRP and its variants have so extensively been studied that it is impossible to mention every important work on the subject here. A bibliography is provided in (Laporte & Osman, 1995). Toth and Vigo (2002) is a comprehensive book on the classical VRP and its variants, describing exact and heuristic methods for their solution, discussing practical issues, and available software. Golden, Raghavan, and Wasil (2008) provide a selection of recent advances and challenges ranging from period VRP and extensions, split deliveries, pickup and delivery problems, multi-objective optimization in vehicle routing, to problems involving a heterogeneous fleet.

There are several examples of using routing models in agriculture. A study from Sweden bears resemblance to our work in the sense that route optimization is applied to outputs of organic agriculture; Bosona et al. (2011) propose a system utilizing information technology and optimization to improve logistics performance of a local food network mainly providing organic fruit and vegetable box-schemes. Though not limited to organic agriculture, Bochtis and Sørenson (2009) propose an application of vehicle routing to agricultural field operations on the farm where field tracks are interpreted as customers in a vehicle routing problem; this model is further extended in (Bochtis & Sørenson 2010) to one with time windows in order to handle field operations that need to be done in a certain time interval. All three works above utilize mobile technologies to some extent. Giaglis et al. (2004) also point out that recent developments in mobile technologies when used in connection with vehicle routing algorithms can help in supply chain management and risk reduction.

3. Formulation and Data

Classically, vehicle routing problems involve one central depot, a set of customers to be served, and a fleet of vehicles each with a given capacity. The objective is to minimize a combination of the number of routes and the travel time.

In our application, the organic market will act as the central depot since all trucks aim the organic bazaar as the destination. The farms supplying organic produce act as the customers to be served. Vehicles will visit farms located in different municipalities around Turkey, where they pick up fresh produce (instead of delivering) and transport them to the organic bazaar in İstanbul. Vehicles are capacitated and distances are symmetric. We use a three index vehicle-flow model due to the greater modelling flexibility offered, we simply minimize the total distance travelled by the fleet. Table 1 contains the definition of the variables and parameters used in the model.

Table 1: Definition of Variables and Parameters

Parameters	
N	number of nodes; *1* represents the organic market and *2* through *n* represent locations of organic farms
K	number of vehicles
c_{ij}	distance between municipalities *i* and *j*
s_i	supply of organic farm *i*
C	capacity of each vehicle
Variables	
x_{ijk}	is 1 if the k^{th} vehicle visits farm *j* after *i* and 0 otherwise
u_{ik}	are variables used in the subtour elimination constraints and are related to the relative order in which municipality *i* is visited on the route of the corresponding vehicle

Source: authors

We use the following formulation based on the truck dispatching problem of Golden (1975):

$$\text{Min} \sum_{k=1}^{K}\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} x_{ijk} \quad (1)$$

$$\sum_{i=1}^{n} x_{ihk} - \sum_{j=1}^{n} x_{hjk} = 0 \quad \text{for } h = 1 \ldots n \text{ and } k = 1 \ldots K \quad (2)$$

$$\sum_{j=2}^{n} x_{1jk} = 1 \quad \text{for } k = 1 \ldots K \quad (3)$$

$$\sum_{j=2}^{n} x_{j1k} = 1 \quad \text{for } k = 1 \ldots K \quad (4)$$

$$\sum_{k=1}^{K}\sum_{i=1}^{n} x_{ijk} = 1 \quad \text{for } j = 2 \ldots n \quad (5)$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n} x_{ijk} = 1 \quad \text{for } i = 2 \ldots n \quad (6)$$

$$\sum_{i=2}^{n} s_i \sum_{j=1}^{n} x_{ijk} \leq C \quad \text{for } k = 1 \ldots K \quad (7)$$

$$u_i - u_j + n x_{ijk} \leq n - 1 \quad \text{for } i,j = 2 \ldots n \text{ and } k = 1 \ldots K \quad (8)$$

$$x_{ijk} \in \{0,1\} \quad \text{for } i,j = 1 \ldots n \text{ and } k = 1 \ldots K \quad (9)$$

A vehicle routing problem has two important pieces of data requirements: the supply and location of each node, and distances between nodes. We obtained the data on farm locations and supplies (weekly transport and sale quantities) from Buğday, the NGO that oversees the marketplace which all farmers supplying organic produce to the organic bazaar have agreed to provide as part of their contract with the municipality. The NGO then uses these quantities for both understanding trends in the domestic market and cross-checking with the organic certification agencies for authenticity. We use data from a week well into the fourth year of the bazaar in autumn; since by then demand and supply quantities have fairly stabilized. Data for the sample week of the first organic bazaar is provided in Table 2.

Table 2: Organic Fresh Produce Supply for the 2. Week of November 2009

Producer Id	Supply Quantity (kg)	Producer Id	Supply Quantity (kg)	Producer Id	Supply Quantity (kg)
1	200	21	755	43	70
2	180	22	2430	44	235
3	386	23	50	45	122
4	2734	24	100	46	679
5	560	25	320	47	105
6	111	26	89	48	100
7	475	27	48	49	308
8	681	28	30	50	505
9	858	29	360	51	162
10	39	30	728	52	50
11	105	31	4400	53	1500
12	67	32	487	54	205
13	190	33	175	55	145
14	163	34	520	56	1405
15	1390	35	157	57	875
16	30	36	40	58	250
17	831	37	650	59	780
18	520	39	265	60	380
19	317	40	550	61	25
20	175	41	1050	62	65
		42	265	64	300

Source: authors

Total supply is 31,747 kilograms. Farmers 38 and 63 are regular suppliers however for this specific week they have not shipped anything but their representatives used products left from the previous week; this can be done for a limited number of products such as apples and onions. Excluding farmers 38 and 63 and combining different farms located in the same municipality into a single node, we reduce the number of customers to be served from 64 to 40. The second piece of data is on distances between municipalities which we obtained from the webpage http://www.illerarasimesafe.com[6]. The calculation there is based upon two information sources: official data from Turkey's General Directorate of Highways and Google MAPS.

In the next section, we present a solution of the problem that enables producers to reduce their unit transportation costs by about 50%. We solve different scenarios using fleet sizes ranging from 4 to 10 trucks each with a capacity of 8 tons.

4. Results

In this section, we present a solution of the problem using two hours solution time and a relative optimality gap of 10%. The solver used is Gurobi 5.5 that employs a branch-and-bound approach with a series of optimizations and heuristics. It also uses parallel optimization techniques which are suitable for today's multi-core microprocessors. The problems have been run on an Intel i7 3.2 GHz processor desktop computer with 6 cores, resulting in 12 parallel threads. Results are summarized in Table 3.

[6] Accessed 26 July 2010.

Table 3: Gurobi 5.5 Solution Obtained in 2 Hours with a 10% Optimality Gap for Vehicles of 8 ton Capacity

Number of Vehicles	Total Distance (km)	Minimum Load (tons)	Maximum Load (tons)	Average Load (tons)	Real Solution Time (sec)	Relative Gap (%)
4*	9,174	7,825	7,993	7,937	7,200	19,9
5*	9,465	217	7,978	6,349	7,200	16,7
6*	9,651	217	7,928	5,291	7,200	11,4
7	9,814	217	7,990	4,535	5,041	9,67
8	10,409	217	7,749	3,968	1,165	8,06
9	11,188	217	7,243	3,527	167	6,12
10	12,295	87	7,355	3,175	19	6,11

Notice that for fleet sizes 4-6, the time limit of two hours is reached without producing a solution within the prescribed optimality gap; in those cases the best solution obtained so far is reported. In Table 3, the solutions terminated due to time limit constraints of 2 hours are indicated with a (*). Others have been solved to optimality or to 10% gap to the best bound. For a fleet size of four, all vehicles are very highly utilized (at least 97%) as a natural consequence of transporting 31.75 tons with 32 tons of total carrying capacity. Figure 1 depicts total distances travelled by the fleet for fleet sizes 4-10. In Table 3 and Figure 1 we can compare different fleet sizes in terms of total distance travelled and a fleet size of 4 seems to be the best option in terms of achieving the smallest total distance. Routes for a fleet size of 4 are displayed in Figure 2.

Figure 1: Total Distance Travelled on all Routes in Scenarios with 4-10 Vehicles

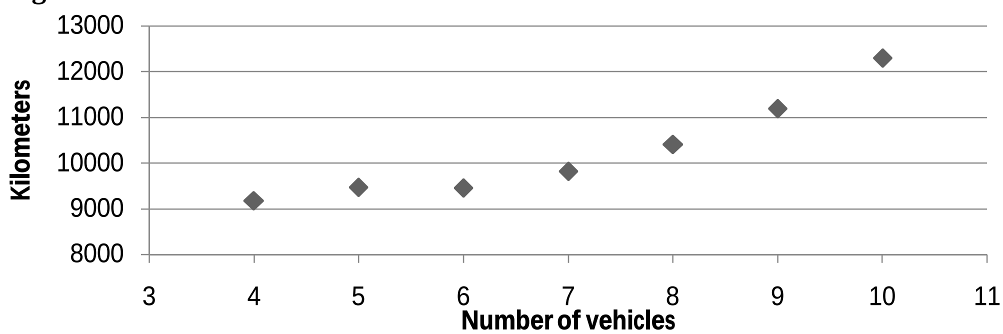
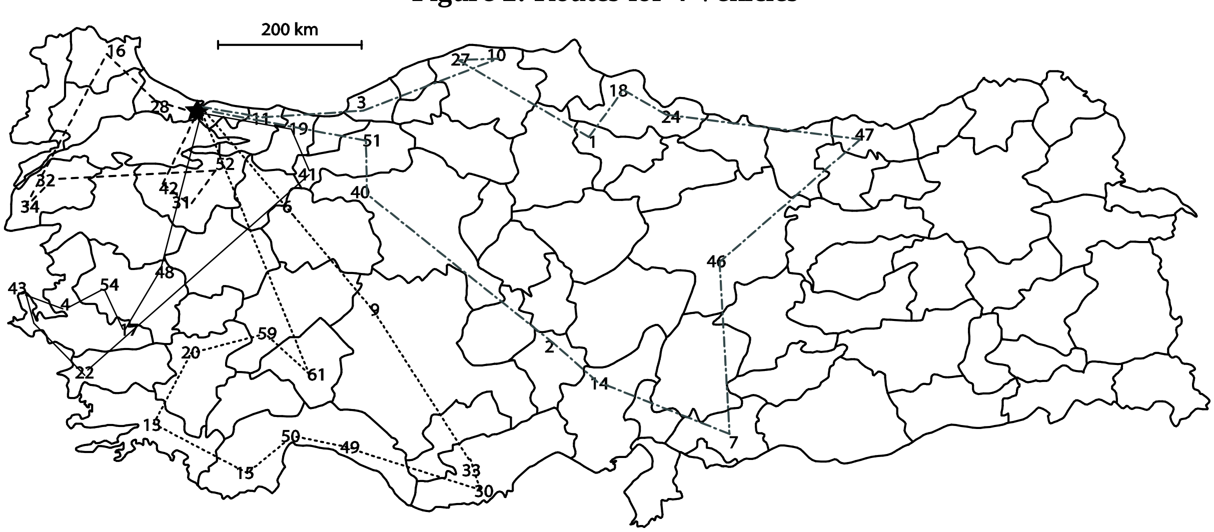


Figure 2: Routes for 4 Vehicles



An economic comparison of these scenarios is needed to understand whether a 4-truck fleet provides an optimum solution in terms of total cost. The economic analysis we present next features a collective arrangement by the farmers.

4.1. Proposed Model and Economic Analysis

In this section we propose a model to be collectively used by the organic farmers supplying fresh produce to the organic bazaar in Istanbul. We list the assumptions of the model first and discuss the implications next.
We assume that a vehicle consumes 15 litres of diesel fuel per 100 kilometres and the cost of fuel[7] is 3.6 L per litre. In addition, we assume that a truck can be bought by a 5-year loan at 19% annual interest for a price of 75,000 L (after salvage value). Per truck maintenance cost is 500 L per month. A driver is employed 2 days per week at a cost of 150 L per day, the co-driver cost is set at 60% of the driver cost. Table 4 summarizes the costs of fuel, financing, maintenance and labour. The scenario with four vehicles is the cheapest solution, the total carrying capacity is 32 tons of which 99% is used up. The next solution that leaves some elbowroom is for 5 vehicles with 40 tons capacity of which 80% is used up (for 6 vehicles with a total of 48 tons capacity, 66% would be filled).

Table 4: Economic Impact of a Collective Transportation Arrangement Based on 5 Trips per Month

Number of Vehicles	Total Distance Travelled (km)	Cost of Fuel (L/mo)	Financing and Maintenance Cost (L/mo)	Cost of Labour (L/mo)	Total Cost (L/mo)	Average Transportation Cost (L/kg)
4	9,174	24,082	9,540	4,800	38,422	0,2421
5	9,465	24,846	11,925	6,000	42,771	0,2694
6	9,451	24,809	14,310	7,200	46,319	0,2918
7	9,814	25,762	16,695	8,400	50,857	0,3204
8	10,409	27,324	15,183	9,600	52,107	0,3283
9	11,188	29,369	17,081	10,800	57,250	0,3607
10	12,295	32,274	18,979	12,000	63,253	0,3985

To build an efficient transportation system for the organic bazaar, we propose that a producers' cooperative be formed to get bank loans for purchasing trucks of appropriate capacity. The cooperative could hire an analyst who each week gets the information on transport quantities from farmers, plans the routes, assigns the drivers, and rotates vehicles when required. For the case of one bazaar per week, i.e., in a 5 trips per month scenario, the hiring of an analyst will increase per kilogram transportation costs by 0.030 L. Still this arrangement reduces transportation costs significantly from 0.60 L to around 0.30 L per kilogram when 5 vehicles are used. In a 10 trip per month scenario, when there are two organic bazaars per week, the impact of hiring an analyst is much less visible, the transportation cost per kilogram only increases by 0.015 L.

For the operation of the system, the farmers send their approximate supply to the analyst at the cooperative several days ahead. The trucks, which are located at the bazaar, are then dispatched according to the solution found by the analyst. Since the farmers are registered to the bazaar at the beginning of each season, farmer locations and the distance matrix can be prepared ahead reducing the time needed for pre-processing of data.

5. Conclusion

The marketplace for organic products established in 2006 in İstanbul helped to alleviate some of the problems of the organic sector by enabling accessibility and increasing availability of organic products. The meeting of farmers, consumers and activists at the bazaar enabled information exchange, knowledge transfer between stakeholders and improved consumer awareness. In this work, we attack the high transportation costs that the farmers and customers of the organic bazaar suffer from and create a model that cuts transportation costs to more than a half. With market-consistent and realistic assumptions, the per kg carrying cost can be reduced from 0.60 L to 0.25 L when 4 trucks are operated by a farmer's cooperative (to 0.27 L when 5 trucks are used). In a market where the average sale price[8] is around 3 L per kg, a reduction in costs of 0.33--0.35 L per kg (i.e. more than 10 % of the sales price) will increase sales and encourage more farmers to take part in organic farming. We employ a vehicle routing formulation and minimise total distance travelled by organic produce. The use of the proposed model will reduce the fuel used in transportation and the resulting carbon emissions, encourage the consumption of local and organic food and reduce costs incurred by small scale farmers. All of these are positive socio-economic and environmental effects.

[7] 2009 prices.
[8] 2009 prices.

Since the NGO Buğday is organizing the bazaar, it can create a roof under which the cooperative can be formed. With a centralized role played, this organization will also be able to track the quantities offered in the bazaar easily.

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