



An ISM approach to overcome the participation barriers in the waste source separation—a case study: Urmia University Campus

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Abstract A procedure developed to identify and facilitate the implementation of waste source separation strategies applicable in higher education centers, as a prerequisite for the expansion of recycling programs. The target materials proper to be separated were selected based on quantitative/qualitative analysis of waste produced on the Nazlou Campus of Urmia University, Iran (as a case study). The barriers to implementation of the program were identified using the interpretive structural modeling (ISM) methodology. Finally, regarding the main obstacles which could be broken down inside the campus complex, an analysis of factors affecting student participation were done. On average, 37.48% of 1.74 tons of waste daily produced on the campus could be recycled. Based on sieve analyses, the categories of non-ferrous metals, glass, and composite packaging have a

wider size distribution (i.e., over 150 to under 80 mm) might lead to improper operation of further mechanical separations and be selected as target materials. The weakness of educational programs and persuading the students are considered the main obstacles. A significant relationship was observed between the three training options, namely “installation of announcements,” “organizing waste management classes,” and “training through holding the exhibition of recycled products” and the student participation in the program (with more emphasis on the last one). Women were estimated to be more likely than men to participate in the program (70 vs 49%). Also, there was a significant relationship between the knowledge and the student’s participation. In other words, strengthening public awareness is essential to increase the participation level.

Keywords Waste management · Source separation · Participation · ISM · Statistical analysis · Nazlou Campus of Urmia University

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Introduction

University campuses as “mini-cities” play an important role in promoting the culture of proper consumption and conservation of resources at the community level by covering a wide range of human activities affecting the environment. Adeniran et al. (2017) identify students as “the mayors of their city.” Considering the role universities play in changing the

patterns of behavior consistent with the sustainable development of the students and extending it to the community, they have undeniable responsibility for environmental protection and the proper use of resources. In this way, at the 1990 international conference in Talloires, France, the first formal statement was made requiring the university administration to be responsible for sustainable development and environmental issues. The execution of waste management programs aimed at conserving energy, materials, and resources intrinsically highlights the necessity for university-level studies (Ebrahimi & North, 2017; Viebahn, 2002). On the other hand, for the implementation of sustainable development strategies, the local and state agencies can have a broad and positive impact on the social and economic development and environmental health of communities through interaction with the university. Therefore, trying to identify the barriers to student participation in the source separation of waste (as a viable solution for the development of recycling and conservation of resources and energy) can be a prelude to solving larger problems in the surrounding urban communities while resolving the waste management difficulties in the university environment (Zhang et al., 2017).

The implementation of the integrated solid waste management (ISWM) system in communities is one of the major challenges in achieving sustainable development (Alhassan et al., 2018; Pujara et al., 2019). This system is a contemporary, well-planned approach to solid waste management that considers how to reduce, reuse, recycle, and handle the remaining waste materials to protect human health and the natural environment. All the discarded materials resulting from the human and animal activities that are usually solid and may not be usable for the producer(s) from an economic and health perspective at that time in the same form, condition, and amount, are referred to as “Solid Waste” (Rhyner et al., 2017). The methods for the management of such waste in environmental terms in order of preference are prevention of waste generation and source reduction, reuse of waste materials before delivery to municipal authorities, separation and recycling of valuable items, production of compost, incineration, and landfilling (Ghaffariraad & Ghanbarzadeh Lak, 2021; Qasim, 2017; Rhyner et al., 2017). To achieve high levels of social participation and develop the capacity to enhance effective public awareness, two

approaches, namely source separation and recycling of waste, are considered important factors in improving the waste management system (Ali et al., 2010; Vassanadumrongdee & Kittipongvises, 2018).

The study of the quantitative and qualitative characteristics of waste production has been reported as the first step in the successful planning of waste management in higher education institutions (De Vega et al., 2008; Fehr, 2015; Smyth et al., 2010; Taghizadeh et al., 2012). However, the studies at universities are very limited compared with similar research at the urban level. Mbuligwe (2002) investigated three academic units in Dar es Salaam, Tanzania (i.e., UDSM, UCLAS, and WRI). The major sources of waste products in this study were the student dormitories, cafeterias, canteens, healthcare centers, faculty and staff neighborhoods, social clubs, offices, workshops, a school located at UDSM University, and the campuses. One of the results of this study was the observation of significant changes in quantity and quality of waste, especially during the final examinations and holidays, and considered the education level of individuals to be effective in the higher per capita waste production.

Owojori et al. (2020) determined the variations of waste components in the University of Venda (UNIVEN) by characterizing the waste generated. Solid waste samples were collected from key activity areas and characterized using the ASTM D5321-92 method for unprocessed municipal solid waste. The recyclable, compostable, and non-recoverable components of the waste generated were found to be 61.7%, 34.4%, and 3.9%, respectively.

Given the fact that the most important component of solid waste produced in educational centers in developing countries is organic materials, Yhdego (1994) explained the appropriate conditions for exploiting this process by examining the windrow-type composting unit at Ardhi University. However, in the study by Okeniyi and Anwan (2012), the percentage of various types of plastics (including polyethylene bags, bottles, and food containers) was reported higher than the food waste at the Covenant University waste stream in Ota, Nigeria. It seems that the mixing of solid waste produced in a public church inside the university has led to an increase in plastic waste on this campus. Hossain et al. (2013) reported both waste paper (27%) and food waste (25%) as the most important waste components in the Jamalkhan Ward educational center in Chittagong, Bangladesh.

Concerning the quantity of waste produced in university centers, a comprehensive study was conducted by Gallardo et al. (2016). The waste production rate at Universitat Jaume I in Spain was estimated equal to 89.50 g/day per capita (including 43.92 g of source-separated waste and 43.90–47.02 g of organic and food waste) during one academic year.

The set of solid waste source separation measures is placed at the top of the waste management pyramid and, if promoted, can significantly reduce the environmental burden imposed on other waste management elements in the lower parts of the pyramid (i.e., incineration and landfilling) (Mason et al., 2004). However, the stringent policies to implement the source separation of waste may result in adverse environmental impacts (Rigamonti et al., 2009). Hao et al. (2020) investigated the waste separation behavior of college students in Zhengzhou (China) under the mandatory regulation and the motivations behind students' behavior. According to the results, influencing factors of college students' waste separation behavior include the convenience of waste sorting facilities, their willingness to separate waste, knowledge of a related field, attitude towards waste separation, peer pressure, and the existence of a reward and penalty system. One of the studies on the feasibility of waste recycling is the research of Smyth et al. (2010). According to this research, about 70% of the waste produced at the University of Northern British Columbia (UNBC) (1.2 to 2.2 tons per week) can be removed by recycling or composting. The measures such as reducing the price of hot drinks for the people who have their ceramic mugs (considering sending 5000 disposable cups per week to the landfill) and encouraging the use of personal towels instead of paper towels in the restrooms, as well as proper site selection for the installation of waste containers for the discarded paper, in his opinion, can be useful in this regard. Moving towards the implementation of the recycling process in universities requires academics to be aware of the waste management processes and their environmental impacts. The implementation of awareness programs and the increased participation of academics in waste management by dividing into two recyclable (including glass, PET bottles, aluminum cans, and tetra pack packaging) and other waste categories at the Azcapotzalco campus of UAM University of Mexico over the past three years have significantly reduced the amount of waste

delivered by this campus to the municipal services unit. The measures taken at the Maldost dormitory of the Slovak Agricultural University in Nitra since 2012 for waste separation have resulted in the separation of 15% of valuable materials from the dormitory waste stream (Báreková & Franeková, 2015). These measures included installing 4 containers for storing plastic waste, 2 tanks for paper, and 2 bins for glass waste at the entrance to this dormitory of 1166 people (with 417 rooms) (all containers of 240 l). The dormitory also has 5 tanks of 1100 l for the storage of food waste. Yang et al. (2021) investigated the municipal waste separation behavior of college students and its influencing factors. Data from a total of 814 questionnaires among college students from sixteen universities in Chongqing were collected. Results showed that publicity, education, and situational factors (convenience of waste separation, waste separation marks, facilities, and surrounding health) have a significant positive impact on the willingness to separate municipal waste.

According to Kelly et al. (2006), one of the factors that prevent the participation of people in universities in recycling programs is the lack of information and knowledge about such programs. A study set out to examine the role of education in students' environmental behavior at the University of Calabar. According to the results, environmental education has the magic wand that can influence positive environmental attitude, behavior, and perception towards positive waste management. The authors recommended that environmental education should be introduced into school curriculums at all levels (Eneji et al., 2019). One of the results Nguyen (2011) found in the case study of East Anglia University, Norwich, England, was that recycling training in the form of lectures, seminars, and workshops can be an effective tool for the promotion of recycling behavior among the students (Zhang et al., 2011).

The previous studies, as observed, mainly focused on (1) determining the quantitative/qualitative characteristics of generated wastes in higher education institutions or (2) identifying and breaking down the obstacles associated with the participation of people in universities in recycling programs. This paper, unlike the previous researches, covers various aspects of waste management including physical analysis of waste stream, evaluation of waste source-separation barriers using ISM, and identifying the factors contributing to the increased

student participation. The target materials proper to be separated from the waste stream were selected based on quantitative/qualitative analysis of waste produced on the Nazlou Campus of Urmia University; then barriers to implementation of the waste source separation program (focusing on the abovementioned target materials) were identified; and finally, regarding the main obstacles which could be broken down inside the campus complex, analysis of factors affecting student participation in source separation of waste (again focusing on the target materials) were done. The studies performed in the urban environments in this regard can be cited by Chauhan et al. (2016) who used the ISM and DEMATEL approach to analyze the barriers to the implementation of the waste recycling program in India. The findings of this study show that the barriers such as lack of funding and subsidies are the most effective barriers to the prevention of infrastructure development needed for the implementation of Indian waste recycling programs. Also, Zamorano et al. (2011) analyzed the barriers, weaknesses, threats, and opportunities for implementing the recycling program in Granada, Spain, and achieved similar results confirming these findings. The reason for using ISM, rather than the methods such as DEMATEL, ANP, and AHP, in the current paper, is the ability to more accurately describe the direct and indirect relationships between the factors and to describe the different dimensions of the problem. Plotting the final digraph and prioritizing and rating each element of a system, the ISM methodology helps managers to better implement the plan and facilitates the understanding of the driver power and dependency of different problem variables for a wide range of users.

Materials and methods

The study area

As a key principle, social studies will be applicable to waste management issues when they are conducted within the community under study and reflect the views and opinions of the affected individuals. Accordingly, the Nazlou Campus of Urmia University was selected as the case study to implement the ISM-based model. The Nazlou Campus of the Urmia University covers an area of about 346 ha with more than 11,000 active students, staff, and faculty members,

and is located at 11 km of the Urmia-Serow road in West Azerbaijan province, northwestern Iran. Urmia University (a public institution), as one of the top 15 universities in Iran, accepts students from all parts of Iran and neighboring countries with bachelor's degrees, master's degrees, and doctoral degrees/Ph.D. Due to the wide range of scientific and cultural levels of the students, the selection of this University as the case study may reflect the average characteristics of Iranian academic society. From the standpoint of waste production sources, the following classification can be considered for this unit (Fig. 1) (Eskandari & Ghanbarzadeh Lak, 2019):

Currently, the daily waste produced on the Nazlou Campus of the Urmia University is transferred to Urmia's No. 2 transfer station located at the beginning of the Urmia-Serow Road, with an average transfer distance of about 20 km (round trip) per service.

Research process

This research is a descriptive–cross-sectional study and the studied population encompasses 11,306 students of the Nazlou Campus of Urmia University. At three-time intervals (i.e., the days of peak attendance of students on campus, namely mid-semester and first days of the week), generated waste was collected by a designated vehicle and weighed. It should be noted that following the national laws, the higher education centers are closed on Thursdays and Fridays, and according to the internal regulations of Urmia University, the management meetings of educational groups or office departments are held in the middle hours of Mondays. Hence, during these times, the attendance of students on the campus will be minimal. In the present study, the sampling was done outside the abovementioned times. After preparing the 100-kg specimens (according to ASTM D 5231, the sample weight should be 91–136 kg or 200–300 lbs.), the constituents were manually separated using five sieves with the opening sizes of 150, 100, 80, 50, and 30 mm and weighed (Table 1). For this purpose, the samples were poured onto the sieve of 150 mm, and the overflow materials were manually separated and weighed. The underflow section was transferred to a sieve of 100 mm and the same operation as before was repeated. The above steps were done for all sieves.

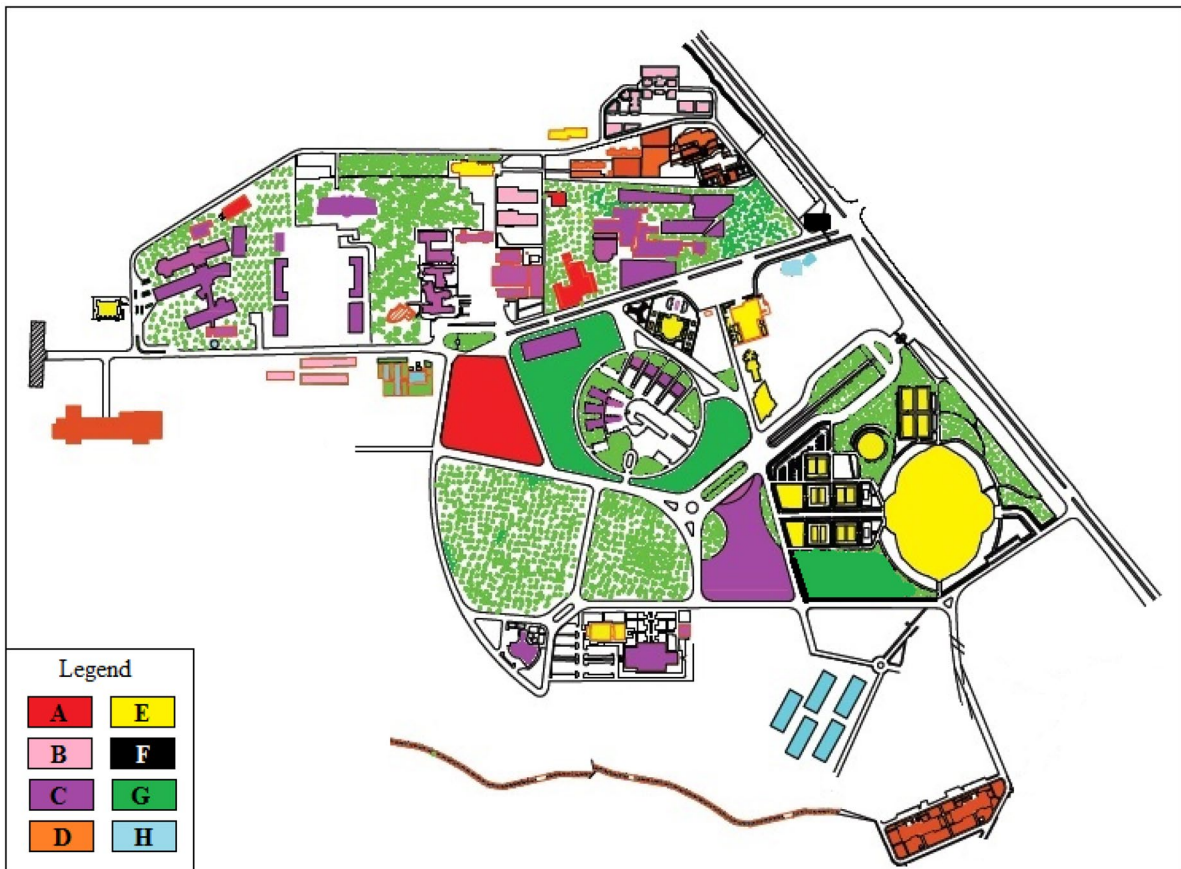


Fig. 1 The location of waste generation sources in the studied area. Note: letters A to H refers to the abovementioned waste production sources. **A** Restaurants and Kitchens: it consists of four main restaurants and nine kitchen units, and the waste produced in this source mainly consists of food waste. **B** Warehouses and central facilities: the waste produced in the warehouses consists of containers, packaging, and industrial waste. **C** Office-educational centers: these include classrooms, libraries, laboratories, auditoriums, office centers, etc. The waste produced in this source generally consists of dry waste (recyclables), and a slight amount of wet waste (organic discards) is

discarded in the cafeterias. In addition, it is possible to produce hazardous waste in some laboratories. **D** Dormitories: there are twelve student dormitories on this campus. The waste produced in this source can be considered semi-municipal waste. **E** Cultural, religious, and sports centers: the major waste produced in these centers is dry waste. **F** Clinic unit: the medical, food and semi-municipal waste is produced there. **G** Greenspace, roads, gardens, and agricultural lands of the Faculty of Agriculture. **H** Other sources: including cattle and poultry units, wastewater treatment plants, banks, barbershops, laundry, and bakeries

By separating the recyclable and compostable materials from the current waste stream, the weight and volume of waste produced in many activity areas of the university can be significantly reduced. To this end, it is necessary to examine the barriers to implementing the waste source separation program (as a preliminary activity to implement the waste recycling policy at the university) and then identify the factors contributing to the increased student participation. As will be mentioned in the continuation of the paper, the main barriers that can be overcome in the Urmia University complex are the

“weakness of the educational programs at the university level” and the “weaknesses in persuading the students.” To remove the mentioned barriers, the opinions of the students should be collected by completing the questionnaires. In the present study, the recently mentioned barriers were identified using the ISM methodology. In order to avoid content duplication, the implementation process of the ISM methodology appropriate to the study environment will be presented in the “[Identification of barriers to implementation of the waste source separation program by ISM methodology](#)” section.

Table 1 Qualitative characteristics of waste produced in the studied area (%)

Size Waste categories	Under 30 mm	30–50 mm	50–80 mm	80–100 mm	100–150 mm	Over 150 mm	Overall content in waste stream
Food/putrescible	100	4.64	12.20	18.02	23.81	3.63	11.45
Paper and cardboard	0	0.29	7.32	11.26	9.52	39.38	12.77
Plastics	0	0.87	19.51	7.66	23.81	27.98	10.77
Textiles	0	0	0	0	0	0	0
Ferrous metals	0	0	0	0	0	1.55	0.44
Non-ferrous metals	0	0.58	4.88	2.25	0	2.07	1.32
Wood and yard trimmings	0	93.33	0	0	0	0	47.26
Glass	0	0	31.71	0	19.05	10.88	5.58
Sanitary waste	0	0	0	54.05	4.76	0	3.67
Special/hazardous waste	0	0	2.44	0	0	0	0.15
Leather and rubber	0	0	0	0	0	0	0
Construction/demolition	0	0	0	0	0	0	0
Electronic waste	0	0	0	0	0	0	0
Composite packaging waste	0	0.29	21.95	6.76	19.05	14.51	6.60

The method used in this study is to assess the knowledge of the target population about current waste management practices on the Nazlou Campus of Urmia University and to identify the desirable community incentives for participation in the waste source separation program in the preparation and completion of the questionnaires. The questions were designed to provide comprehensive information on people's attitudes towards the quantity and quality of waste produced, sources of production, method of storage, and transport of waste to the disposal site. The interviewees were selected from both genders from undergraduate, postgraduate, and doctoral degrees and different years of entrance, and the sample population was estimated based on the Cochran formula for the limited number of communities (Israel, 2012). The Cochran formula is used to calculate the essential sample size for the required level of precision, confidence level, and the estimated proportion of the attribute present in the population. The Cochran formula is most suitable for a large population. If the population is small then the sample size can be reduced slightly. This is because a given sample size provides proportionately more information for a small population than for a large population (Eq. (1)) (Nanjundeswaraswamy & Divakar, 2021).

$$n = \frac{\frac{z^2 pq}{d^2}}{1 + \frac{1}{N} \left(\frac{z^2 pq}{d^2} - 1 \right)} \quad (1)$$

where n : sample size; N : population size (11,306 students); z : percentage of standard error based on the acceptable 95% confidence level (here 1.960); p : proportion of population with specified attribute (0.5); q : (equivalent to 1-p) proportion of the population with no specified attribute (0.5); and d : the degree of confidence with desirable probability accuracy (here up to 10%).

One hundred seventeen questionnaires were distributed (9% confidence degree) for identifying the factors influencing the increased participation of students in the source separation program. The validity of the questionnaire was assessed through a survey of experts (experts and professors from the faculty of engineering, environmental health, and statistical sciences), and confirmed by removing existing defects and removing or adding some questions. The reliability of the questionnaire was also assessed using Cronbach's alpha coefficient. The total Cronbach's alpha for the present study was 0.841 and for different parts of the questionnaire based on the number of items, the dependent variable of student participation in the source separation program was 0.677, and the independent variables of training methods, environmental awareness, and knowledge, and strategies for encouraging the students were 0.753, 0.716, and 0.750, respectively. Then, the data collected through the questionnaires were analyzed at both descriptive and inferential levels (using SPSS software). At the

descriptive level, the frequency distribution tables and the circular and column diagrams were used. At the inferential level, the chi-square and Pearson tests were used to determine the relationship between the variables of each hypothesis. Also, using the Kramer coefficients and Kendall’s coefficient of concordance, the relationship between the independent and the dependent variables and the intensity of correlation coefficients were separately determined using the Mann–Whitney test tables.

Results and discussion

Quantitative and qualitative analysis of waste produced on Nazlou Campus of Urmia University

Like most higher education institutions, Urmia University is also involved in a wide range of operational, educational, and research activities that produce large quantities of solid waste. The daily solid waste production rate on the Nazlou Campus of Urmia University, on average, was 1740 kg/day (SD=181.84 and variation range=440). The waste production per capita was also calculated to be 133.84 g/day per capita (Table 1 and Fig. 2).

As can be seen in Table 1 (last column), the highest share of waste stream on the Nazlou Campus of Urmia University belonged to the “wood and yard trimmings” category at 47.26%. The area of green

space and farms in the studied area is approximately 190 ha and, according to the current trend of university waste management, in the time of year when tree pruning waste is slightly produced (i.e., fall and winter), they are collected with other wastes in a mixed manner (during this time, the major part of the wood and yard trimming waste category consists of the waste from the lawn mowing on the campus). During the tree pruning, the resulting woods and shoots along with the lawn mowing waste are separately collected and openly burned after drying.

According to Table 1, 37.48% of the waste stream produced on the study campus is recyclable (about 650 kg/day). Therefore, applying the source separation policy can improve the quality of materials sent to the recycling centers while reducing the burden on the waste collection center, and thus, in addition to the conservation of resources and the environment, greater financial benefits will be earned by the waste management of the university.

As it is evident from Fig. 2, most of the recyclable waste produced on the Nazlou Campus is over 150 mm in size, and this finding can greatly help in the design of separation sieves. On the other hand, since about 68% of food/putrescible waste has dimensions less than 50 mm, two successive separation sieves (trommels) with 150- and 50-mm openings can be used to maximize waste separation efficiency at material recovery facilities (MRFs) (note that wood and yard trimming waste as the dominant category in the campus waste stream is 30–50 mm in size). In this

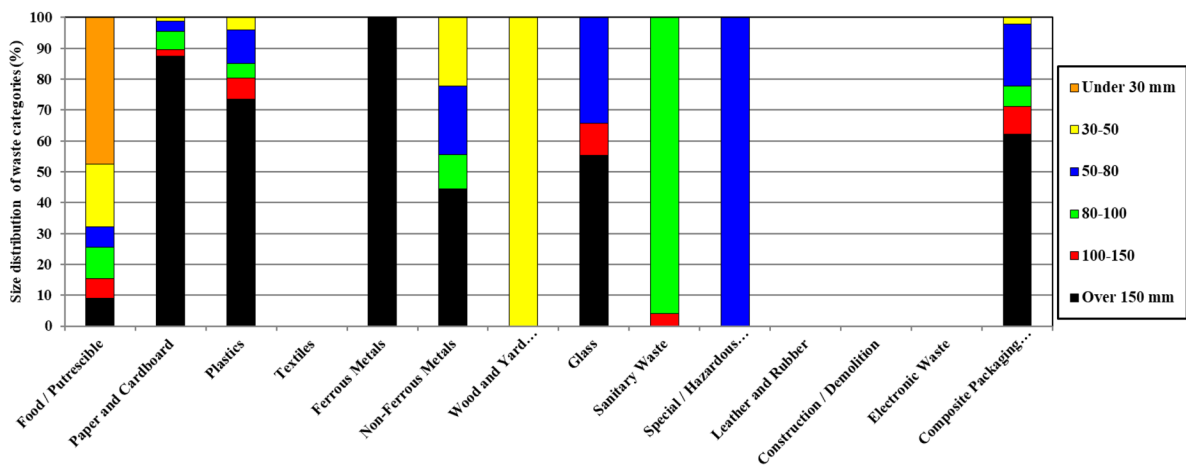


Fig. 2 Size distribution of waste categories

way, the 150-mm sieve overflow is transferred to the separation line, and the 50-mm sieve underflow can be directly used to produce the compost.

Based on the results of Rigamonti et al. (2009), it is not preferable to impose rigorous policies to implement the source separation of wastes in the studied area, at least at the beginning stages. Hence, it is proposed to take the advantage of MRF plants to separate valuable materials from the mixed waste stream. Again, referring to Fig. 2, the categories of non-ferrous metals, glass, and composite packaging have a wider size distribution than other recyclable wastes and, therefore, the source separation policies on the study campus should focus on these categories. In other words, it is possible to separate waste paper and cardboard, plastics, and ferrous metals at high-efficiency MRF facilities (they can be easily separated by the sieves and other mechanical equipment due to the uniform screening), but the non-ferrous metals, glass, and composite packaging wastes are available in different sizes, and by implementing the source separation program for such waste, the greater environmental and economic benefits will be earned by the waste management of the university. It is evident that by removing the barriers to student participation in the separation of target materials from other wastes, the quality of recycled products can be improved in the later stages of the plan.

Identification of barriers to implementation of the waste source separation program by ISM methodology

In order to analyze the relationships between the barriers to a successful implementation of the source separation program on the Nazlou Campus of Urmia University, a questionnaire was designed and provided to professionals, experts, university service providers, and students. After the data collection, the barriers were analyzed and rated using the ISM methodology, and the structural models and the driver power-dependency diagram were plotted. It should be noted that the survey in this section is different from the questionnaire mentioned in the research method section. The survey outputs in the present section identified seven key barriers that were analyzed in eight steps, as follows.

- (a) The main barriers to the implementation of the waste separation program on the Nazlou Campus of Urmia University are identified as listed in Table 2.
- (b) The second step of the ISM methodology is to select a contextual structure appropriate to the problem under study (one of the five structures described in Janes, 1988). The Intent structure is used here to identify the factors that influence

Table 2 The main barriers to implementing a source separation plan in the studied area

Barrier code	Title	Description
B1	Lack of confidence in university service management	Students are not sure that the revenues associated with the implementation of the plan will be consumed for their welfare or to protect the university environment
B2	Weakness of the educational programs at the university level	The lack of educational and informational programs at the university level regarding source separation of wastes
B3	Weaknesses in persuading students	Investigating the effective factors to encourage students to drive towards successful project implementation by meeting their expectations
B4	Inadequate university funds	Lack of sufficient budget may preclude the implementation of the plan due to the lack of required infrastructure (e.g., special bins to collect recyclables)
B5	Low awareness of students	Insufficient knowledge of students about the importance of source separating wastes and waste management issues
B6	Weaknesses in university service infrastructure	Weaknesses of university officials to improve the environmental conditions
B7	The low willingness of students to participate in the project	Investigating the preventive factors in the student participation rate as a key element of the implementation of the source separation program

the purpose a program or company is pursuing. A commonly used contextual relationship in this type of structure is the “Would help to achieve” term.

- (c) In the third step, the structural self-interaction matrix (SSIM) is developed. To develop this matrix, if the problem in question has n factors, $\frac{n(n-1)}{2}$ questions are asked. The method for filling the elements will be a choice of the following four items. If $j > i$ (i is the number of barriers listed in the first column and j is the number of barriers listed in the first row of the SSIM):

- V: Barrier i would help to achieve barrier j (or barrier i leads to barrier j);
- A: Barrier j would help to achieve barrier i ;
- X: Barriers i and j lead to each other;
- O: None of the barriers i and j are related to each other.

In the present paper, the SSIM has 7 factors and as a result of receiving 21 survey questions, Table S1 (presented in Supplementary Material) was obtained.

- (d) The fourth step is the preparation of the initial reachability matrix. For this purpose, adjacency matrix A will be developed based on the SSIM matrix. For the preparation of the matrix A , if the corresponding cell in the SSIM has a (V) value, $A_{ij} = 1$ and $A_{ji} = 0$. Similarly, if the corresponding cell has a (A) value, $A_{ij} = 0$ and $A_{ji} = 1$. In this way, if the corresponding cell has a (X) value, $A_{ij} = A_{ji} = 1$, and if the corresponding cell has a (O) value, $A_{ij} = A_{ji} = 0$. In the following, the initial reachability matrix M is computed as $M = A + I$, where I is the identity matrix with the same dimension as the matrix M .

- (e) Step 5: Checking transitivity of initial reachability matrix and preparation of final reachability matrix. With the exponentiation of the matrix M according to the rules of Boolean algebra (i.e., $1 + 0 = 0 + 1 = 1$, $0 + 0 = 0$, $1 + 1 = 1$, $1 \times 0 = 0 \times 1 = 0$, $1 \times 1 = 1$), the indirect relations will appear in the final reachability matrix (Eq. (2) and Table 3). For example, according to Table S1, the interviewees did not consider any relationship between the barriers of inadequate university funds or B4 and the low willingness of students to participate in the project or B7 (the corresponding cell in Table S1 has an O value). However, in the matrix M_{Final} (where indirect relations also appear), barrier B4 leads to barrier B7 (number 1 in the corresponding cell). Referring to Fig. 4, which will be described below, it is observed that the barrier B4 affects B3, B3 affects B1, and ultimately, B1 affects B7. Therefore, an indirect link appears between barriers B4 and B7 when checking the transitivity of the initial reachability matrix.

$$M_{Final} = (A + I)^n$$

$$s.t : (A + I)^{n-1} < (A + I)^n = (A + I)^{n+1} \tag{2}$$

- (f) The sixth step involves the partitioning of the final reachability matrix and determining the level of factors, where a table is first created based on the final reachability matrix in three columns titled Reachability set, Antecedent set, and Intersection set. The reachability set includes the elements and other elements which the relevant element (corresponding row) helps to obtain (plays a role). Therefore, to fill each cell in the reachability set column, the corresponding row is considered. As such, if the number 1 is found, the corresponding element will be written. The ante-

Table 3 The final reachability matrix (M_{Final})

Barrier	B1	B2	B3	B4	B5	B6	B7
B1	1	0	0	0	1	0	1
B2	1	1	0	0	1	0	1
B3	1	0	1	0	1	0	1
B4	1	1	1	1	1	1	1
B5	0	0	0	0	1	0	1
B6	1	0	1	0	1	1	1
B7	0	0	0	0	1	0	1

cedent set is also a set of elements that lead to the desired element. Finally, the intersection set represents the common elements in the two previous columns. The element for which the reachability set and intersection set are equal will have the highest level. After the first level was determined, this element is deleted from all the remaining rows, and the above operations are repeated to rate all the elements (Table S2).

- (g) The seventh step involves the development of the conical matrix, an initially directed graph (digraph), and the final directed graph. After defining the barrier levels (Table S2), the final reachability matrix is rewritten so that the first row of the table is assigned to the first level of the previous step, the second row to the second level, and so on. This matrix is called the conical form of the reachability matrix. Now, based on this matrix, the initial digraph can be drawn, where the vertices contain the representative numbers of the study barriers. If in the final reachability matrix, $M_{Final}(i, j) = 1$, an arrow will be removed from the element i and enter the element j . The initial digraph will be very complex (Fig. 3). In the next step, all indirect relationships will be eliminated to yield the final simplified digraph. Finally, the numbers are replaced by the name of the barriers (Fig. 4).
- (h) Finally, in the eighth step, the driver power-dependency graph is plotted and the results are interpreted (Fig. 5). The driver power of each element is the sum of the corresponding row numbers in the M_{Final} matrix and denotes the elements that it helps to achieve (including the element itself). The dependency of each element is also the sum of the corresponding column numbers in the M_{Final} matrix. According to the driver power-dependency graph, the barriers can be divided into four categories.

Autonomous factors: these factors have low driver power and low dependency. These factors can be considered almost isolated from the system because they have little relationship to other elements.

Dependent factors: these factors have low driver power but are highly dependent.

Linkage factors: these factors have high driver power and dependency. Making any changes

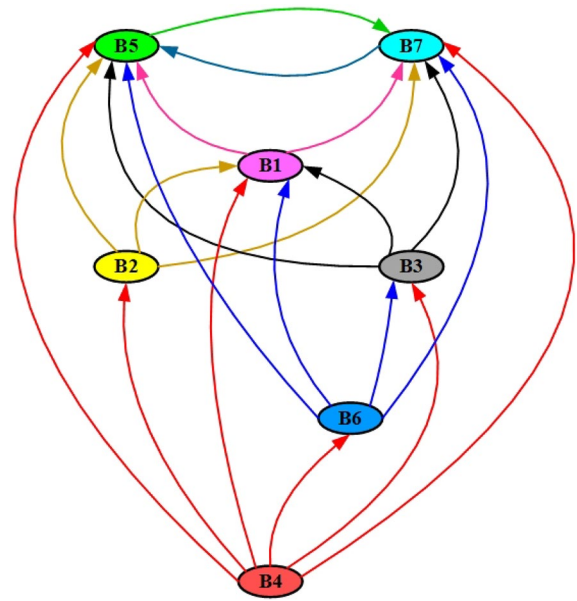


Fig. 3 The initial digraph

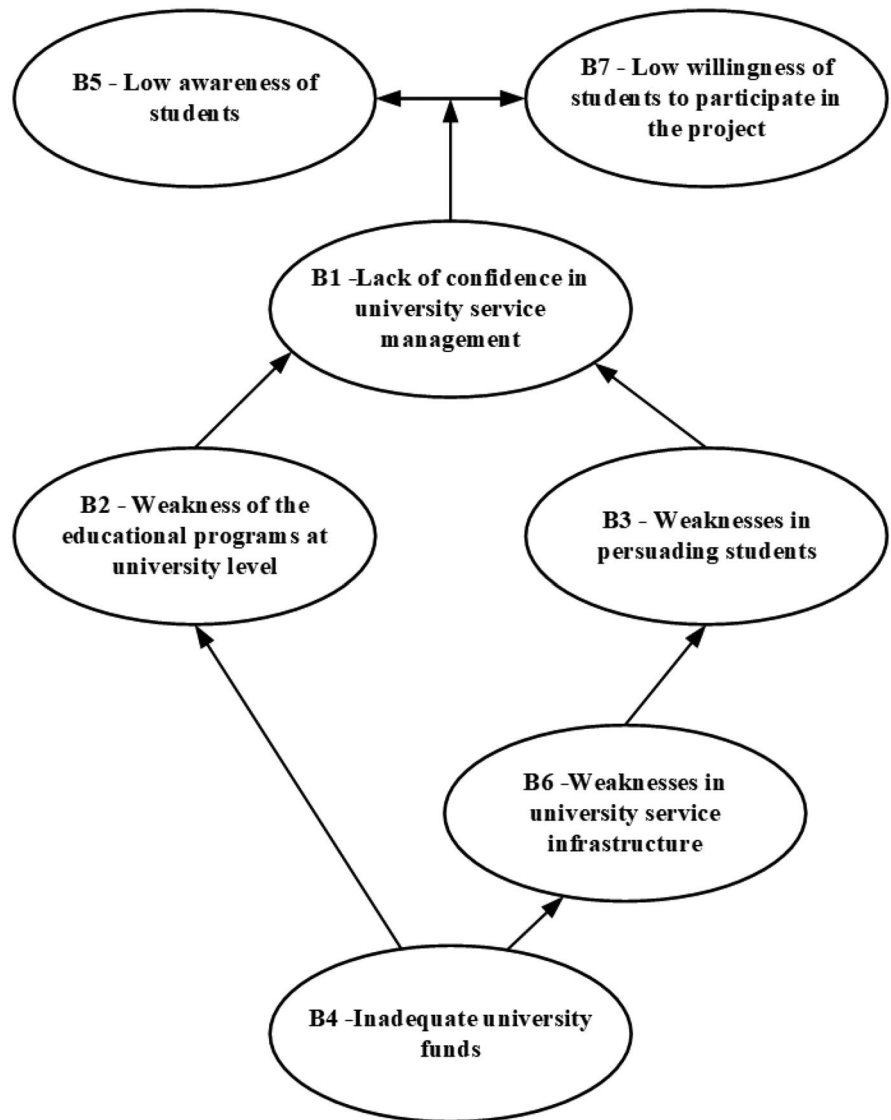
to these factors will have significant effects on other elements and may have feedback on them.

Independent or driver factors: these factors have high driver power and low dependency. These factors affect other elements but are less affected. It should be noted that the median in each axis was used to partition the driver power-dependency graph space into the four aforementioned areas (Singh et al., 2003, 2007).

According to Fig. 5, the factors B2, B3, B4, and B6 are independent or driving factors in the present study and have high driver power and low dependency, which means that they influence other factors but are not highly affected. Therefore, the barriers to the implementation of the waste source separation program on the Nazlou Campus of Urmia University can be removed by strengthening these factors. The factors B1, B5, and B7 are also considered the dependent factors that have low driver power but high dependency and are affected by the aforementioned driving factors.

Given the main purpose of the present paper (to provide strategies for greater student participation in waste source separation) and considering the financial and infrastructural constraints of the study campus

Fig. 4 The final digraph



(where removing the constraints is beyond the scope of this study), the main focus of the paper in the following is to find the ways for stimulating the factors B2 and B3 (i.e., weaknesses of the educational programs at university level and weaknesses in persuading the students) by completing and the statistically analyzing the questionnaires.

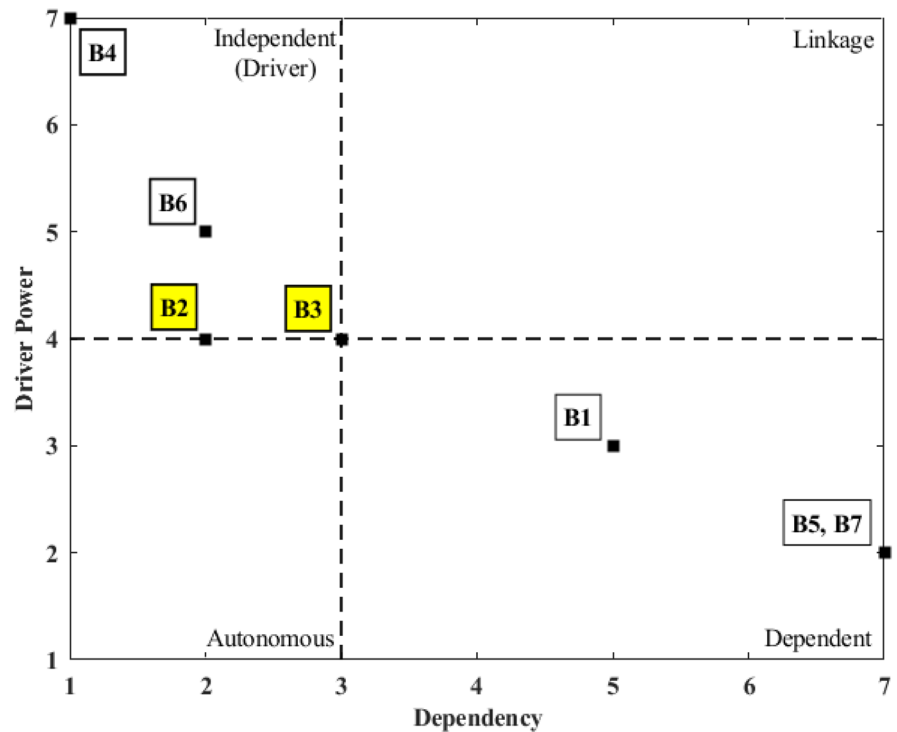
Analysis of factors affecting student participation in source separation of waste

The characteristics of the statistical population studied in this paper are presented in Table S3, which

covers all academic degrees available at the university for both genders.

In this study, the willingness and motivation of students to investigate participatory behavior are measured, considering the social trust in the educational environment, satisfaction with the current status of university waste management, environmental responsibility of individuals, and finally, encouraging strategies for increasing student motivation. The awareness of the students of the general discussion of the source separation of waste (i.e., segregation of dry and wet wastes) was measured in the first question of the questionnaire. Based on the answers, the

Fig. 5 Driver power—dependency graph



mean values and the coefficient of variations of the data are 4.54 and 0.50, respectively (it should be noted that the scores given by the respondents to each numerical question range from 1 to 9, and the higher the score, the more attractive the subject). In other words, the student's information in this area is moderate to low. However, to verify the interviewees' claim about their knowledge of the source separation (answer to the first question), the amount of target materials compared to the total waste produced was asked in the third question of the questionnaire. The average percentage of recyclable waste stated by the students was 47.98% compared to 37.48% extractable from Table 1 (including paper and cardboard, plastics, ferrous metals, non-ferrous metals, glass, and composite packaging waste). This indicates the inadequate accuracy but appropriate validity of responses (inadequate knowledge of students on waste management issues).

The second question evaluates the set of actions taken by university officials to inform students about the benefits of waste source separation. The values of mean, standard deviation, and coefficient of variation of the responses were 2.71, 1.82, and 0.67, respectively. The obtained information indicates the

poor performance of the officials in the notification. The fourth question explores the extent of the efforts of the university management to provide training to the students for the separation and segregation of wet and dry waste. The average value of 1.96 responses indicates the inadequate performance of university service officials. The standard deviation and coefficient of variation of the data were 1.53 and 0.78, respectively. The fifth question of the questionnaire consists of five sections that provide students with several effective strategies and methods for the training and notification of the officials about the source separation of waste. The suggested methods are (1) face-to-face training; (2) installation of announcements, banners, advertisements, and brochures; (3) posting short environmental messages on the university's website; (4) organizing waste recycling and management classes as two optional courses; and (5) training through holding an exhibition of recycled products. The means of data were 4.36, 4.83, 4.21, 5.09, and 5.27, and the coefficients of variation were 0.65, 0.54, 0.63, 0.59, and 0.55, respectively. According to the results, training through holding an exhibition of recycled products is the most effective solution. Figure 6 shows the percentages of each of the

response levels from 1 or very low to 9 or very high for answers to each section of the fifth question.

As seen in the figure, in most cases, except for waste recycling and management classes as two optional courses and training through holding an exhibition of recycled products, the interviewees generally found the proposed training method ineffective (due to the high percentage of the response level 1 to the components of question 5). At the end of the questionnaire, however, the interviewees were asked to include their suggested training method. The materials written in this section indicated that the students did not consider providing the training in this area and that they were concerned mainly with providing the required context by the officials, such as placing sufficient trashcans for the separation in the dormitory kitchens and delivering special garbage bags to the rooms of dormitories. These findings are in agreement with the results of Yang et al. (2021) and Hao et al. (2020).

In question #6, the respondents were asked to identify the best of six methods for encouraging the students to separate target materials from other wastes. The methods offered for this work include (1) conducting the student inspection to ensure that the program revenue is spent on the student’s welfare; (2) informing students about the adverse effects of inappropriate waste management on the environment; (3) awarding prizes such as free use of campus amusement rides; (4) providing food such as pasta, beans, canned food; (5) supplying writing stationery or detergents such as washing powder, shampoo; and (6) provision of daily food tickets for a certain weight of recycling items. The obtained results showed that the means of the data were 5.26, 6.14, 6.39, 6.26, 6.07, and 6.25, and the coefficients of variation were 0.45, 0.35, 0.40, 0.44, 0.46, and 0.44, respectively. In other words, the respondents chose the daily food tickets for a certain weight of recycling items as the best way to encourage the students. As in the previous question,

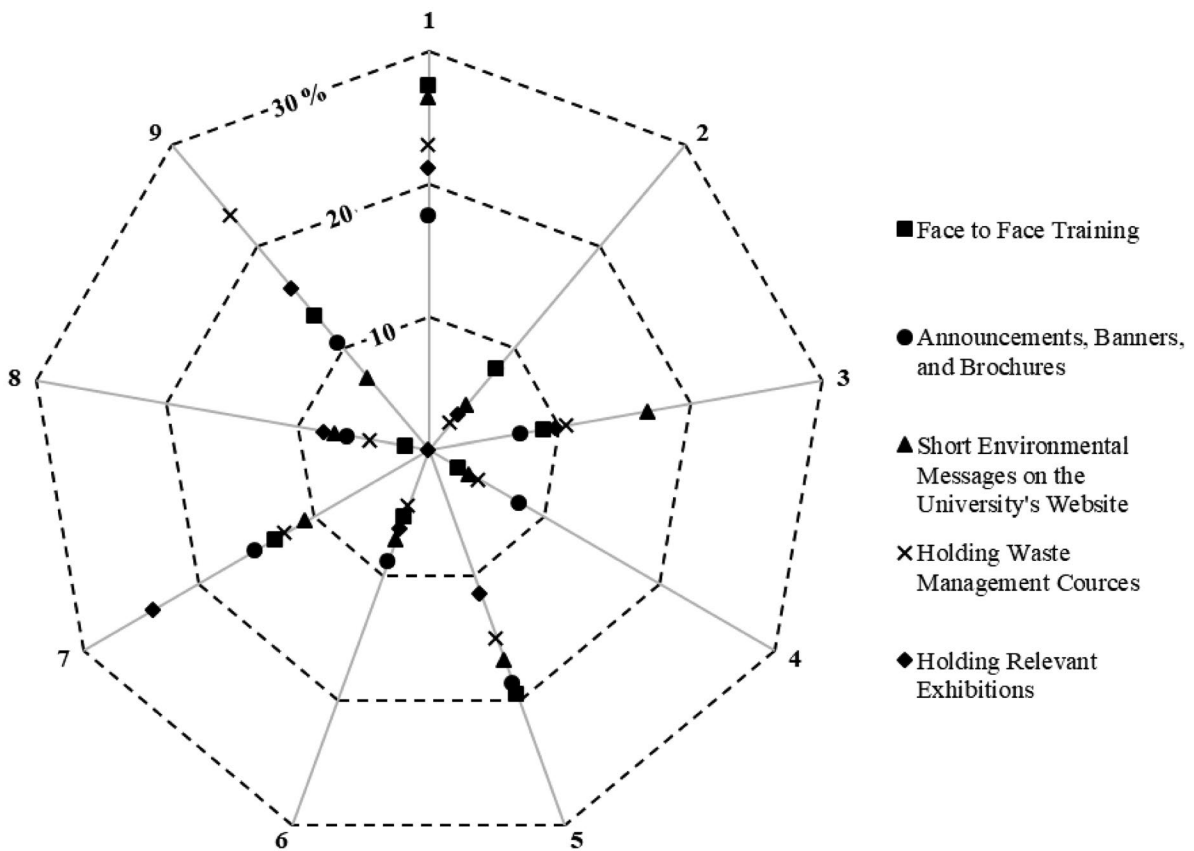


Fig. 6 Percentage of each response level (from 1 to 9) presented to the different sections of question #5 of the questionnaire

the percentages of each of the response levels to the sixth question sections are summarized in Fig. 7.

In this figure, unlike Fig. 6, the respondents generally rate the incentive option at a very effective level (level 9), unless the option in question has no financial benefit (including the awareness and assurance of proper use of the resulting resources). The results of the Pearson chi-square test and the Mann–Whitney test tables also confirm that with the high awareness of the issue of waste source separation, the students considered supplying the writing stationery, detergent, etc., for a certain amount of separated waste to be effective in advancing the program (in agreement with the results of Hao et al. (2020)).

In the seventh question, the most important factors to increase student participation in the implementation of the source separation program were studied at the Nazlou Campus of Urmia University. The following fourth factor was considered the top factor in increasing participation: (1) trusting other fellow students in the program implementation and emphasizing that a healthy environment in the university will be maintained if they cooperate; (2) fulfilling service official's commitments to the separate management of separated wastes (by students) and not mixing at the time

of collection and transportation; (3) scheduling and accurate planning of waste collection separated by the relevant authorities; (4) ensuring the return of income from the program to the welfare affairs of students; (5) inspections done by the students on the correct execution of the plan. The means of data were 4.87, 5.74, 5.74, 6.91, and 6.01, and coefficients of variation were 0.44, 0.42, 0.39, 0.34, and 0.41, respectively. It was found that the distrust of the expenditures with the highest score is the main concern of students participating in the program implementation.

In the following, the relationship between research variables and participation rate in the source separation program was statistically tested. For example, the assumption of the relationship between the gender of the interviewees and their participation in the program is examined in full detail. Then, the results of other hypothesis tests will be presented. It should be noted that the demographic characteristics of the interviewees (i.e., gender, age, education level, and educational status or total average) and their participation in the waste source separation program were significant only for the gender variable and other factors were not significantly affected the increased environmentally responsible behavior of academics.

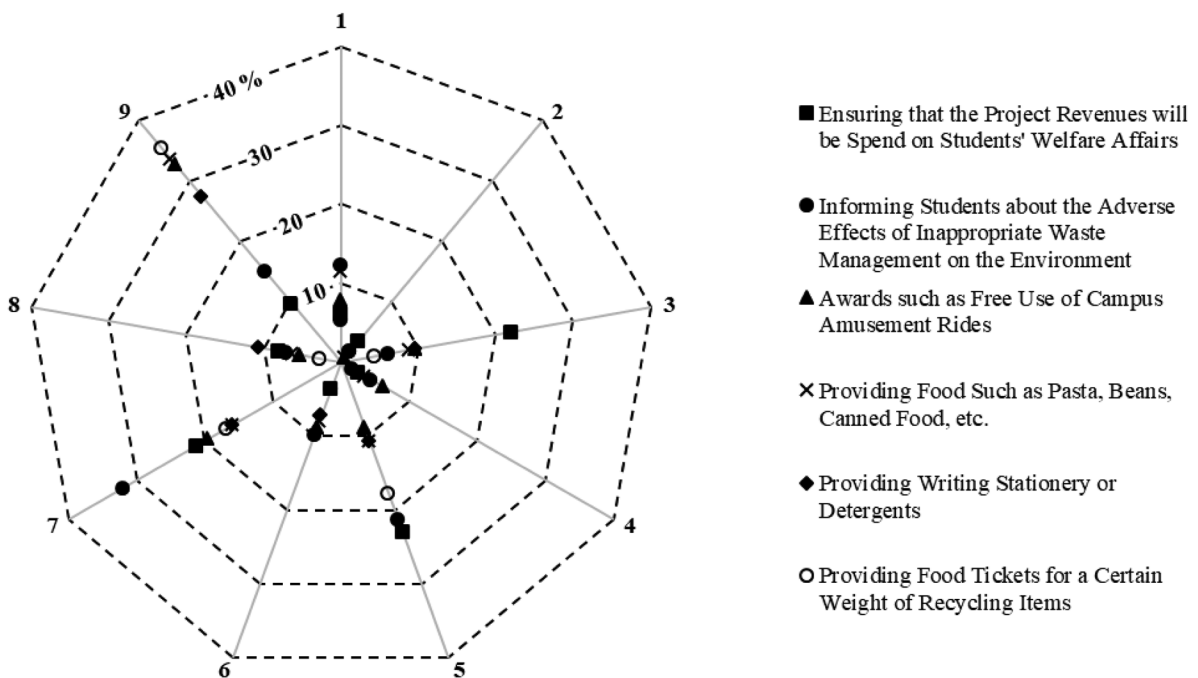


Fig. 7 Percentage of each response level (from 1 to 9) presented to the different sections of question #6 of the questionnaire

The chi-square and Pearson tests were used to examine the hypothesis of the relationship between the gender of the interviewees and the participation level. Moreover, the nonparametric substitution for this test (i.e., the Mann–Whitney U test) was used for the comparison since the assumptions of the independent t -test and the normality of the data distribution were not fulfilled.

H1: The gender of the interviewee affects their participation in the program or H1: $P \leq 5\%$

H0: The gender of the interviewee does not affect their participation or H0: $P > 5\%$

According to the results of the Pearson chi-square test (i.e., 13.704) in Table S4, the null hypothesis is rejected at the 0.01 significant level and it can be stated with 99% confidence that the H1 hypothesis is confirmed. Also, the Kramer coefficient of correlation (0.348) shows that the intensity of the relationship between the variables is moderate with a positive direction, and according to the Mann–Whitney U table (Table S5), women are more likely than men to participate in the program.

Regarding the other tests, the results are as follows:

- (a) According to the results of the Pearson chi-square test (26.720) with 16 degrees of freedom and Kramer coefficient of correlation (0.224), the null hypothesis is rejected at the significant level of 0.05 and it can be stated with the 95% confidence that there was a significant relationship between the awareness and the participation of students and the higher the awareness, the higher the participation level. It is in agreement with the results of Eneji et al. (2019), Hao et al. (2020), and Kelly et al. (2006).
- (b) In order to accept or reject the hypothesis that there is a relationship between the training method preferred by the interviewee and their participation level, each of the training options was examined using the Pearson chi-square tests. The significant levels of test for the methods of “installation of announcements, banners, advertisements, and brochures”; “organizing waste recycling and management classes as two optional courses”; and “training through holding an exhibition of recycled products” were 0.013, 0.030, and 0.042, corresponding Kramer coeffi-

cients were 0.262, 0.250, and 0.244, and Kendall coefficients of concordance were 0.165, 0.287, and 0.293, respectively. This represents the moderate to low relationship between the variables. Given that the significance level of the test is less than 0.05 for the listed items, it is concluded that there is a meaningful relationship between the three abovementioned training options and the participation level in the program by the students, and the interviewees believe that by presenting the training methods at the university level, their participation rate will be increased (in agreement with the results of Nguyen (2011)). It should be noted that there was no significant relationship between the “face-to-face training” and “through posting short environmental messages on the university’s website,” and the student participation in the program.

- (c) The satisfaction of the students with the information provided by the university officials regarding the source separation of waste on the Nazlou Campus of Urmia University is at a low level with a mean score of 2.71 out of 9. The results of the significance level of the Pearson chi-square test of 0.985 (equal to 6.225 and Kramer coefficient of 0.117) indicate that there is no significant relationship between the mentioned factor and the participation level in the program and both variables are independent of each other.
- (d) For examining the hypothesis that there is a relationship between the evaluation of the students of the effectiveness of university service management efforts in providing the context for the wet and dry waste segregation program and their participation, the significance level of the Pearson chi-square test was 0.788 (equal to 11.348 and Kramer coefficient of 0.158). As such, it is concluded that there is no significant relationship between the two cases and they are independent of each other. According to the available statistics, the university service management effort to implement the program was rated as very low and poor with a mean score of 1.96 out of 9. In other words, by understanding the shortcomings of the service providers, the academic community is obliged to perform environmental tasks (based on results of parts c and d).

(e) Each of the encouragement options was examined in terms of the relationship between the options and the participation level. The significance levels of the Pearson chi-square test for the methods of “conducting the student inspection to ensure that the program revenue is spent on the student’s welfare,” “providing food such as pasta, beans, canned food,” “supplying writing stationery or detergents such as washing powder, shampoo,” and “provision of daily food tickets for a certain weight of recycling items” were 0.031, 0.029, 0.003, and 0.021, respectively. Also, the Kramer coefficients of 0.249, 0.250, 0.283, and 0.256, respectively, indicate a moderate to low relationship between the variables. Given that the significance level of the test is less than 0.05, it is concluded that there is a meaningful relationship between the four abovementioned incentives and the student participation level, and the student participation rate will be increased in the program with the abovementioned incentive methods. It should be noted that no significant relationship was observed between the incentives of “informing students about the adverse effects of inappropriate waste management on the environment” and “awarding prizes such as free use of campus amusement rides (e.g., free tickets for the recreational-sports complexes of the university)” and their participation in the program.

Conclusion

The main objective of this research was to provide a method to implement source separation policies in higher education centers. For this purpose, quantitative and qualitative analysis of generated waste was determined in Urmia University. Urmia University was selected as our case study due to encompassing a wide range of scientific and cultural levels of the students. Besides, the educational indicators of West Azerbaijan province (location of Urmia University) were similar to the average of Iran in the time of conducting this research (i.e., number of students per 100,000 inhabitants, and student’s participation in public institutions). The results of the present study showed that, on average, 1.74 tons of waste is produced daily on the Nazlou Campus of the Urmia

University, consisting of 1021 kg of biodegradable waste, 187 kg of plastic waste, 222 kg of paper and cardboard, 97 kg of glass, 115 kg of composite packaging waste, and 31 kg of metal scrap. Therefore, the major part of the waste produced at Urmia University has the potential to be composted or recycled. Based on the waste screening results, the categories of non-ferrous metals, glass, and composite packaging have a wider size distribution than other recyclable waste, and therefore, the source separation policies on the campus understudy should focus on these categories (target materials). It is due to the fact that obligatory separation into several categories will not be successful for students who participate in the program for the first time.

The main strategy to increase the efficiency of recycling operations is to implement waste source separation policies. The results of identifying and rating barriers to the implementation of the source separation program by the ISM methodology indicate the high importance of the barriers of the “weakness of the educational programs at the university level” and the “weaknesses in persuading the students.” Training and encouragement have always been the key elements in the success of public participation programs, so the students are expected to incorporate the principles learned at the university into their personal lives and professional activities, and the level of environmental responsibility is increased. The results of statistical tests also show that there is a significant relationship between the knowledge and participation of students and the higher the knowledge, the more the participation rate.

Most of the students on the Nazlou Campus of Urmia University were willing to participate in the source separation of waste (with a high score of 7.56 out of 9), but due to the lack of knowledge in this field (with the mean score of 4.54 out of 9) and lack of planning related to the issue in the university services sector (with the very poor score of 1.96 out of 9), as well as the inadequate information and lack of training provided by the university management (with the low score of 2.71 out of 9), the source separation is not systematically performed. In other words, the provided answers show the dissatisfaction of students with the actions taken by the university complex regarding the source separation. This result was also one of the identified driving barriers to the ISM method that influenced other factors,

and removing this barrier can play an important role in the successful implementation of the waste source separation program. The interviewees also believe that the most effective way of notification and training is to hold the exhibition of recycled products at the university level. However, the main concern of the interviewed students, especially in the dormitories, was the provision of necessary context by service officials, such as placing sufficient trashcans to separate waste at university and dormitory kitchens, as well as delivering special waste bags to dormitories. Presenting the daily food tickets for a specific weight of recycled items is the best way to encourage students to maximize their contribution to the source separation of waste. Given the scores set by the students for each of the encouragement methods, it is inferred that due to the infancy of environmental measures in Iran and the limited experience of social actors in this field, one cannot currently expect that individuals (even educated ones) have significant participation in the source separation of the waste without fulfilling their material expectations. Among the various factors that may lead to increased student participation in the program implementation, the interviewees considered “ensuring the return of program income to student welfare affairs” as the most important factor. In other words, due to the poor performance of university officials in the field of notification and training and the failure to see the evidence of their seriousness in the future, the student’s trust in the university institution was relatively low and this had a considerable impact on their participation in the program. Finally, encouraging students as environmental ambassadors for producing less waste at home and striving to increase their participation in the separation of recyclable components can offer a bright prospect for proper waste management in the future of Iran.

Author contribution Vahid Eskandari: data collection, analyzing. Mehdi Ghanbarzadeh Lak: literature search and review, manuscript writing. Milad Ghaffariraad: manuscript editing.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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