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Evaluating energy harvesting from water distribution networks using combined stakeholder and social network analysis

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ABSTRACT

The chance of success in implementing a new project in a water distribution network (WDN) significantly depends on the behaviour of the involved stakeholders. In this paper, the feasibility of installing the micro-turbines in WDNs for generating hydro-power energy is studied from the stakeholders' perspective. Stakeholders' analysis (SA) and social network analysis (SNA) are performed to methodically recognise the environment and the relationships among stakeholders. 18 stakeholders at the local, regional, and national levels were identified and their representatives were interviewed. In SA, the power, interest, access to information, and satisfaction from the current condition of the system were evaluated for each stakeholder. The Water and Wastewater Company and Ministry of Energy were found as the stakeholders with the highest power and interest. Unexpectedly, the Regional Electricity Company was discovered with medium power and low access to information. In SNA, cooperative and non-cooperative relationships between stakeholders were analysed and an assessment was made for the role of each stakeholder in their social network, through four centrality metrics. The correlation between SA and SNA results suggests that SA factors could be estimated using the SNA metrics.

1. Introduction

In modern communities, urban water distribution networks (WDNs) are one of the most important infrastructures. These networks are responsible for supplying, treatment, and distribution of water. In an urban area, many stakeholders are related to a WDN, e.g., consumers, water utility companies, local government, etc. All stakeholders have complex relationships with each other, resulting in a social network of stakeholders. Any new plan must be agreed upon by all stakeholders (or a majority of them) before it can be implemented, since each stakeholder has the ability to advance the project or obstruct it, based on their roles, influence, utilities, degree of satisfaction, etc. Nevertheless, studying the affecting stakeholders and their relationships is necessary for implementing the plan, successfully.

Hydropower is expected to play a vital role in limiting the global temperature increase to 1.5° Celsius (°C), as it offers essential contributions such as power generation, flexibility, and dependable support for power systems. Although hydropower has the highest share of installed capacity (44%) and power generation (60%) among renewable sources [1], its full potential has yet to be fully harnessed. Nonetheless, hydropower remains an economically advantageous option as one of the most cost-effective forms of renewable electricity, featuring levelised cost of electricity values that rank among the lowest across various power generation technologies. However, it faces various challenges, e.g. altered water flows caused by climate change, social and environmental consequences, an aging fleet, and evolving power system demands that necessitate hydropower plants to operate in manners different from their original designs [2]. Small hydropower (SHP) has gained prominence in global development strategies due to its capacity to adapt to local requirements and conditions, making it particularly suitable for remote rural regions with low-density energy demands. It serves as an effective means to reduce greenhouse gas emissions and enhance energy independence. Between 2013 and 2022, global installed and potential capacity of SHP (<10 MW) has increased by 12% and 25%, respectively [3]. WDNs have the capacity to generate clean and sustainable hydroelectric energy. Traditionally, in high-pressure zones, pressure reducing valves are often installed; however, micro-turbines can take their place. This equipment is able to generate clean and renewable energy from the water flowing inside the pipes, while reducing the excess pressure. Numerous studies have been carried out on technical feasibility of using micro-turbines as a mean of energy harvesting in WDNs [4] with major focus on pressure management [5–7],

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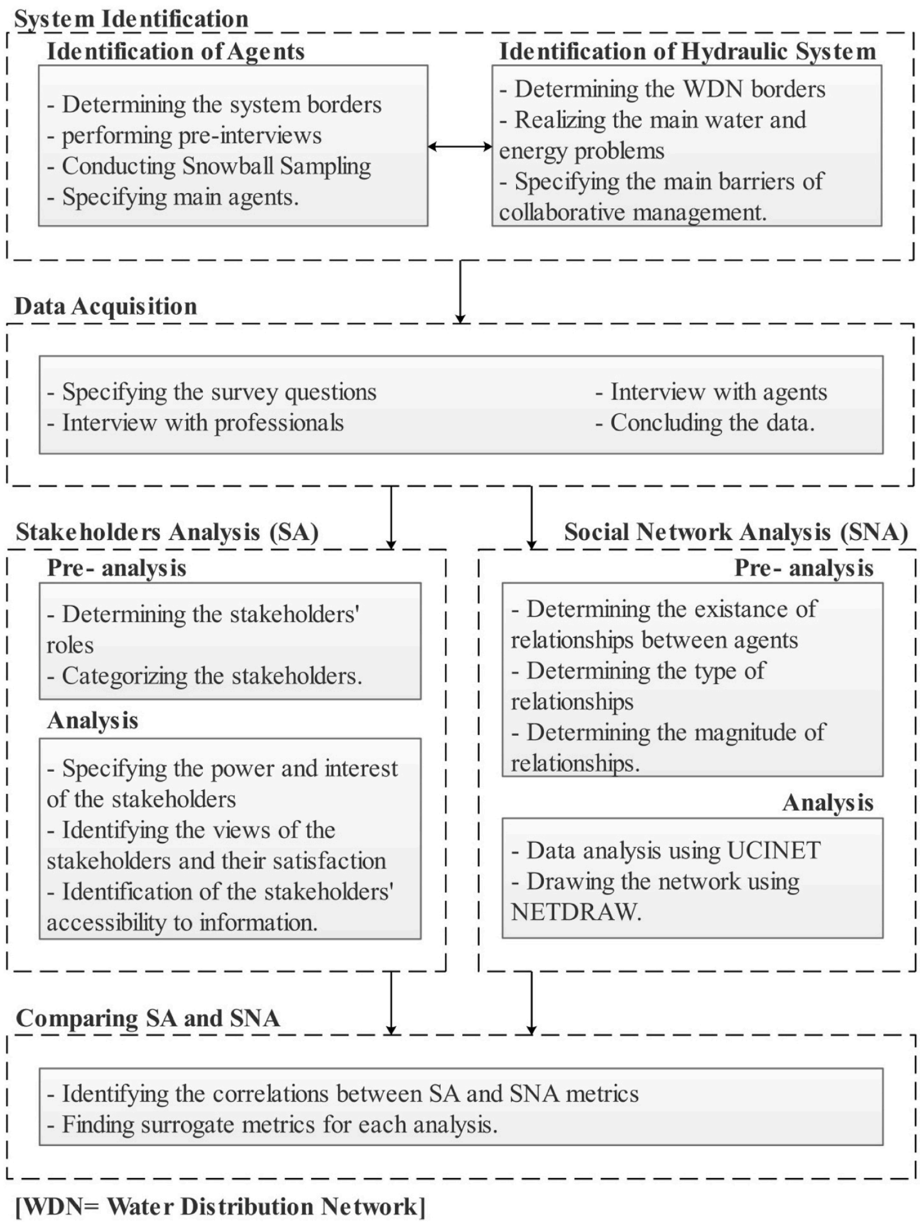


Fig. 1. Flowchart of the proposed methodology.

energy recovery [8–10], economic benefits [11–13], and leakage reduction [14]. Optimal locating of the micro-turbines, e.g. placing at pressure reducing valve locations, and optimal selection of hydropower facilities are typical subjects in these researches [15–17]. However, the socio-technical aspects did not get enough attention. Each stakeholder may be impacted by the deployment of micro-turbines in a WDN, positively or negatively. Recognising the stakeholders and their contribution is an important undertaking given the potential conflicts that may arise between the many stakeholders. Stakeholder Analysis (SA) and Social Network Analysis (SNA) are powerful tools to identify potential clashes and collaborations, finding the best option to convince the stakeholders.

1.1. Stakeholder analysis (SA)

Stakeholders could be any individual, group, and/or organisation who may have affecting roles in project activities and have something to gain or lose if conditions change or remain the same [18]. For handling the challenge of choice in a complex system, participatory approaches are usually utilised. Investigating the characteristics of stakeholders and their connections are the main aims of these methodologies. Hence, SA may be carried out in three steps based on the goals of the analysis: 1) Identifying the stakeholders; 2) classifying and ranking them according to their roles and weights; and 3) inspecting current relationships amongst stakeholders.

In a WDN, identification of the stakeholders could be done by looking at hydraulic (functional), economic, social, and environmental aspects. The second step is to point out the characteristics of stakeholders in comparison with others, e.g., their roles, powers, interests, priorities, access to information, etc., which indicates their importance in the decision-making process. Moreover, stakeholders can be categorised in taxonomies from different points of view. As an instance, in a WDN, they can be clustered into national, regional, and local groups [19, 20]. In this step, each stakeholder's priorities will be determined regarding their main roles and goals of engendering. Finally, cooperative or non-cooperative relations between the stakeholders will be established.

In SA qualitative data are gathered and analysed in a methodical

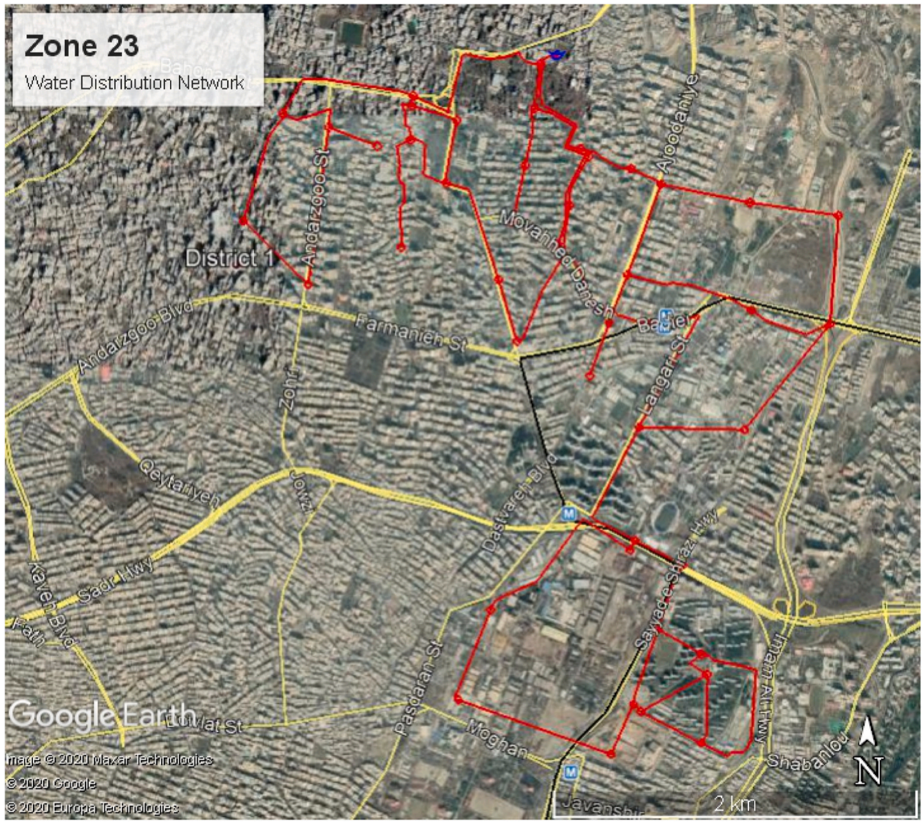


Fig. 2. Main components of the WDN in the study area in Tehran, Iran.

manner, such as semi-structured interviews and power-interest matrices, to determine whose objectives are relevant to the process of implementing a programme or policy.

In recent years, SA has focused on a range of water governance problems [21]. [22] used expert interviews to construct an agent-based and hierarchical model of stakeholders to analyse their behaviours. They developed a model for predicting the age distribution, capacity, and cost changes in a WDN [23]. identified 8 main stakeholders in a drinking water supply system in China and found both the government and the water company as the most important stakeholders [24]. analysed 18 stakeholders (in 5 categories) for supporting local water security planning in Jordan [20]. characterised the stakeholders in rural water supply in Ghana, Malawi, and Bolivia [25]. carried out a stakeholder analysis to improve the agricultural water management policies in Malta [26]. recognised the interaction between 10 stakeholders in water management in Morocco [27]. completed a SA accompanied by a SWOT analysis to improve regional nature conservation in a case study in Germany.

By describing the properties of the system, identifying the stakeholders with a purpose in those aspects, and determining the stakeholders' goals for participation in the decision-making process, SA can help understand complex urban systems. Although SA has often been used to solve problems in natural resources management, it has the potential to facilitate the decision-making processes in urban WDNs, regarding the importance of stakeholders' involvement.

1.2. Social network analysis (SNA)

Social Network Analysis (SNA) is the process of illustrating, modelling, and analysing a community of agents using a network structure with nodes and linkages that symbolises each agent's relationships. Both agents and relationships are equally important in the SNA paradigm. Additionally, SNA might be suggested as a useful method for analysing the role of social interactions, which could not be immediately apparent. Consideration may be given to graph theory and related assessments when utilising SNA for social modelling. By precisely evaluating their connections, SNA may determine the true positions of various actors in a governance network [28].

Typically, WDNs involve a number of agents that may be represented in a social network structure [29]. SNA may be used to provide a more thorough portrayal of the agents and their interactions in various WDN management scenarios. SNA can be used for identifying key agents, leading to more accurate planning and management processes. An effective SNA may be used to comprehend the main actors and dissemination of information in a system.

The social network may be utilised to examine the features of management [30]; and [31]. [32] studied the social network of 70 organisations involved in the water governance of a river catchment in Tanzania [33]. analysed the social network of stakeholders in a watershed in Canada and highlighted the role of bridging organisations in helping the municipalities to collaborate indirectly [34]. investigated the relationship between water governance stakeholders in a river basin in the USA during three periods of conflict, negotiation, and agreement [35]. provided strategies for NGOs to exit from water and sanitation networks in Nicaragua [36]. incorporated cultural theory into social network analysis to improve water pollution management in the Philippines. USAID carried out social network analysis as a part of the water, sanitation and hygiene (WASH) program in Ethiopia, Uganda, Cambodia and Kenya [37], and India [38]. [39] studied the participatory social network of water governance in the UK [40]. analysed 14 actors participating in the water governance of a river basin in Iran.

Few works have been done inclusively to recognise and analyse the stakeholders in water distribution networks [29]. used the SNA as a tool to analyse the implications of WDN failure in Florida, USA. Studying the projects employed in WDNs proves that accompanying stakeholders with the aims of the project can play an important role either in fail or in the success of the project. Usually, SA is considered as a method to focus

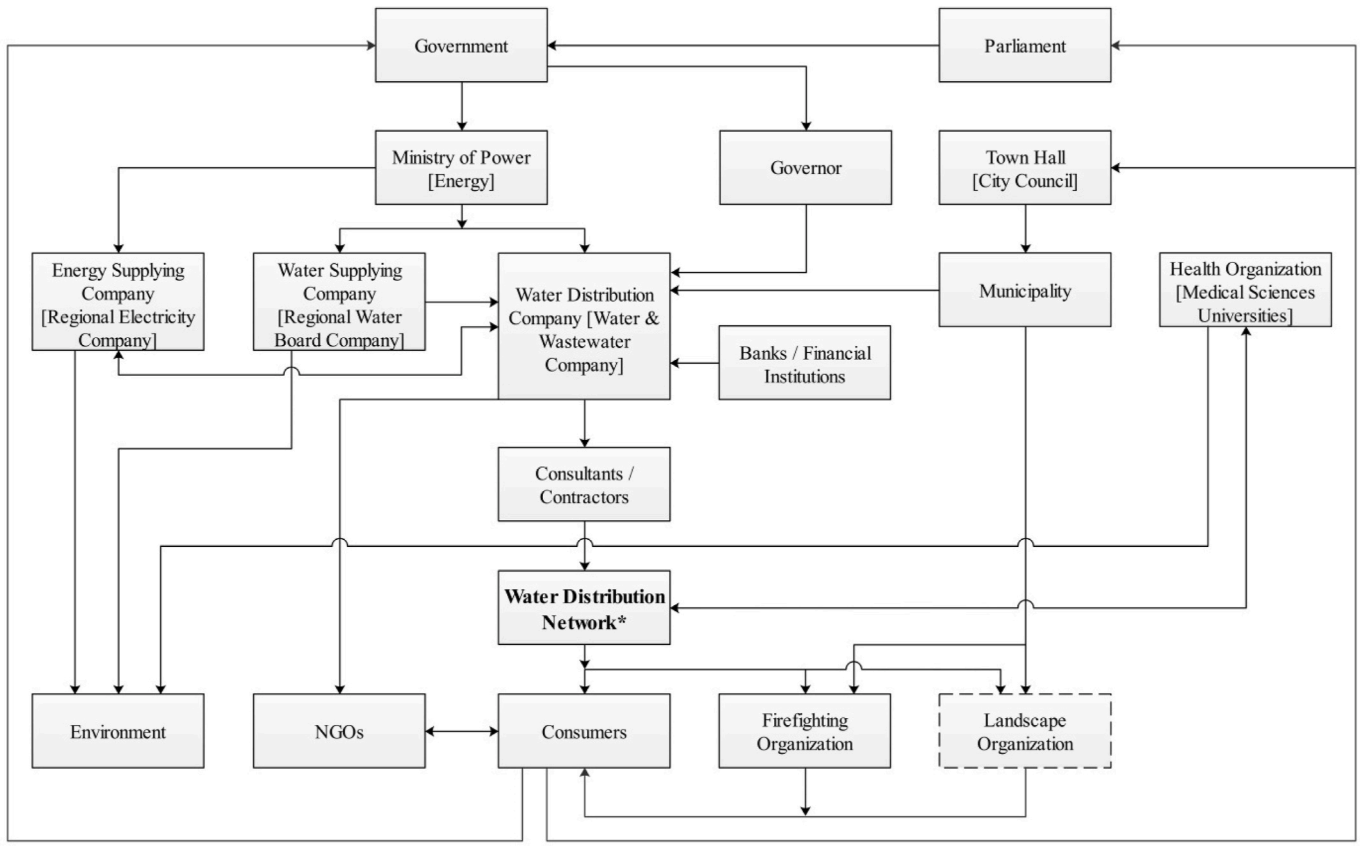


Fig. 3. Organisational relationship of the main stakeholders.

on each stakeholder neglecting their relationships. On the contrary, SNA takes the relationships between stakeholders into consideration to identify their importance. SA and SNA have been successfully combined in some water governance problems [19,41,42]. In this paper, for the first time, SA and SNA have been carried out to evaluate the energy harvesting plans in a WDN. The results of this study give a profound understanding of the agents in a WDN with various powers, interests, satisfactions, etc. SA and SNA may help the decision-makers to choose the best scenario and improve the chance of success particularly in an urban project.

2. Methodology

As mentioned earlier, the main focus of this research is to integrate SA and SNA to better understand the stakeholders' behaviour in an energy harvesting programme in a WDN. In this section, initially the case study was recognised and explored (Section 2.1). Then the potential agents are identified via pre-interviews (Section 2.2). Knowing the main stakeholders, their representatives and water professionals are interviewed to acquire data about them and their interactions (Section 2.3). SA was then carried out to determine the characteristics of each stakeholder solely (Section 2.4). Then SNA was conducted to unveil the relationships between stakeholders and the way they affect each other in a hydropower generation programme in a WDN (Section 2.5). Eventually, the results were compared and combined in Section 2.6. Fig. 1 presents the methodology applied in this paper. In the following the details of the methodology are presented.

2.1. Recognising the study area and its boundaries

The boundaries of the study area and also the list of stakeholders should be identified simultaneously, in a way that all main stakeholders are included in the geographical boundaries.

In this paper, the case study is the urban WDN supplied by one of the reservoirs in Tehran City, Iran (Fig. 2). The WDN has a 6.2 km^2 area and serves a population of 188,000 inhabitants. The difference between maximum and minimum elevation in the WDN is almost 200 m, which leads to utilising 13 pressure reducing valves (PRVs). The reservoir feeding the network has a capacity of 31,600 m^3. The main operator of the WDN is Tehran Province Water and Wastewater Company (TPWW).

The city has a steep topography leading to WDNs with considerable amounts of excess pressure, particularly in low-elevation zones. Traditionally, PRVs are deployed in the network to dissipate the excess pressure. Each PRV has the potential to be replaced by a micro-turbine in order to harvest hydro-electric energy from water flowing in the pipes [6].

2.2. Recognising the agents

Simultaneously by determining the boundaries of the systems, it is necessary to identify the agents. The main stakeholders have been identified by using prior research or interviews, and only high influence stakeholders were taken into consideration. In this study, all stakeholders were identified, and their main characteristics were determined. It was carried out in accordance with the few studies that have been conducted on this subject. The findings of these studies were used to prepare a preliminary list of agents.

Utilising the "snowball" method for data collection [43], some water experts were asked to add other important agents to the list to make it complete. In addition, the level of the problem is limited to WDN, therefore, the actors who play a role in water allocation (such as farmers, factories, water supply sources, underground aquifers, etc.) were not considered. As a result, the key stakeholders were determined and shown in Fig. 3.

Table 1
A list of all identified stakeholders in the present paper.

Group	Stakeholder Name	Role in energy management in a WDN	Abbreviation
National	Planning & Budget Org.	National policy making, allocating budgets for urban infrastructure projects	P&B
	Parliament	Preparing and deciding the supportive acts to facilitate the investment in renewable energies (e.g. tax exemptions, …)	Parl
	Ministry of Energy	Determining the operational rules of WDNs, allocating the water resources, producing the electricity in power plants, determining the energy tariffs	MoE
Regional	Water & Wastewater Company	Designing, constructing, and operating the facilities for supplying, treatment, transmitting, and distributing of drinking water, implementing plans for electricity generation in WDNs	WWC
	Regional Water Board Company	Protecting the water resources quality and quantity, water supply, and transmission for WWC, following the MoE water allocation policies	RWBC
	Regional Electricity Company	Supplying needed energy for water system facilities (e.g. pump stations), buying the hydro-power with supportive prices	REC
	Environment Protection Agency	Supervising the environmental effects of infrastructure projects, encouraging renewable energy generation and pollution mitigation projects	EPA
	Health Organisation	Water quality control in WDNs	HO
	Banks/Financial Institutions	Investment and funding the profiting projects (e.g. renewable energy projects)	BFI
Local	Governance	Implementing government policies at the local level	Gov
	City Council	Policy-making in urban management through appointing the mayors and supervising the municipalities, intervention in WDNs' operation as a shareholder of water companies	CC
	Municipality	Facilitating the construction and operation processes of WDNs projects, it has two sub-organisations: Firefighting and Landscape	Mun
	Firefighting Organisation	Consumer of water in firefighting	FO
	Landscape	Consumer of water in urban landscapes	Lan
	Contractors	Implementing the infrastructures projects (e.g. construction, procurements, and installing the small hydro-power generators)	Cntr
	Consultants	Technical studies, detailed design, and supervising infrastructure projects (e.g. designing small hydro-power generators)	Cnsl
	NGOs	Public supervision on the quality of WDN services, push to reduce the water prices, communication between public and authorities	NGO
	Consumers	The main customers of WDNs, direct/indirect supervision of government, parliament, and city council through voting in the election	Cnsm

The *government* and the *parliament* (Parl) serve as two primary decision-making elements in the democratic governance systems. In most situations, the annual budget allocation to government agencies is under the control of the parliament, which is also in charge of overseeing the performance of the government. As a result, the parliament will not support a programme if it causes unhappiness among the public or seriously conflicts with higher legal laws.

Also, the government is in charge of running the nation's affairs. With the parliament's assent, it collects taxes and spends the money on the nation's essential requirements. By deciding the supportive tariffs for buying electricity, both government and parliament can support clean energy generation projects. In this study, *Planning and Budget Organisation* (P&B) is considered a representative of the government. Through the relevant ministry, the government puts its policies on the administration of WDNs into practice. This ministry may take the names as the ministries of water, energy, or the environment. This ministry, known as the *Ministry of Energy* (MoE) in Iran, manages to provide the water necessary for the drinking, agricultural, industrial, and environmental sectors. MoE also is in charge of supplying electrical energy, nationwide, by running the power plants. Generating power in small plants, which helps to respond to the peak demand, is highly preferred for MoE.

Regional Water Board Companies (RWBC) and Provincial *Water and Wastewater Companies* (WWC) execute the national policies of the MoE at the regional level. RWBC is responsible for protecting water resources in terms of quality and quantity. They provide raw water for urban uses to WWCs. In addition, WWCs are one of the essential agents handling water treatment and distribution at the provincial level. In the meanwhile, WWC is a major energy consumer, supplying pumping stations, treatment plants, administrative buildings, etc. As mentioned before, they have the potential of generating hydro-electric energy in WDNs. The *Regional Electricity Company* (REC) is one of the most notable agents, which provides the power required for WWC's operational activities. *Governorates* (Gov) are responsible for implementing government programmes and policies at the local level. Governors aid in accelerating and facilitating the completion of infrastructure projects. Due to the high cost of water projects, sometimes it gets hard to pay for them from executive bodies' budgets. Obtaining a loan from *Banks/Financial Institutions* (BFI) is the typical approach in these situations. These institutions prefer to invest in high-benefit projects, e.g. power plants in which government pays for the produced electricity with supportive prices. *Consulting engineers* (Cnsl) and *Contractors* (Cntr) in the water network execute the projects according to WWC's demands. The consultants research the plans' feasibility, and carry out their detailed design. Contractors build the structures, and procure and install the required facilities for energy harvesting projects. The domestic *Consumers* (Cnsm) are the most significant local stakeholders in a WDN, paying the water bills, they contribute a small fraction of the water costs. They also affect the government, parliament, and *City Council* (CC) decisions by voting in the elections.

City councils directly appoint the mayor and decide the *Municipality*'s (Mun) annual budget. The Municipality is responsible for urban administration, and is in close cooperation with WWC to implement the water projects. Moreover, the Municipality is a shareholder of WWC, and runs two other stakeholders of WDN; *Firefighting Organisation* (FO) and *Landscape* (Lan) organisation. The Firefighting Organisation is also one of the crucial water users in the WDN. Even though the amount of water used for firefighting is negligible compared to the total consumption of the consumers, it is essential to always maintain enough pressure in the hydrant valves. Maintaining the minimum pressure required for firefighting should be considered in every pressure management programme. WDNs in certain cities are also used to deliver water to public green spaces, which is why Landscape organisation is also mentioned as an agent.

Non-governmental Organisations (NGOs) have connections with both the WWCs and the public to deal with social concerns. They can bring

Table 2
Characteristics and value scales from the survey.

Characteristics	Definition	Point scale
Power	The ability of stakeholders to impact the energy management and energy harvesting projects in WDN	1 (very little power) 5 (very significant power)
Interest	The degree to which the energy management and energy harvesting projects in WDN have an impact on the institutional interests of the stakeholders	1 (very little interest) 5 (very significant interest)
Satisfaction	The stakeholder's perspective on the current state and operation of energy management in WDN	1 (very little satisfaction) 5 (very significant satisfaction)
Access to information	The simplicity or complexity with which information about energy management in the WDNs may be accessed	1 (very hard to access) 5 (very easy to access)
Institutional relationships	Identification and classification of formal relationships among the stakeholders	Magnitude: 0 (none) 5 (very strong) Nature: + (cooperative) – (non-cooperative)

the public voice to the authorities, whilst helping the authorities to convince the public about the benefits of a project. All energy-related activities in a WDN have impacts on the environment. The *Environment Protection Agency* (EPA) is the related stakeholder in charge of reducing the emission to the environment. The two most significant environmental advantages of using hydro-turbines to generate power are the reduction of the need for fossil fuels and also greenhouse gas emissions. The *Health Organisation* (HO) consecutively monitors the water quality in WDNs and ensures the health of consumers. In this case study, Medical Sciences Universities take the mentioned responsibility.

Eighteen stakeholders were identified who might have a direct or indirect impact on energy management in the case study WDN. Categorising the stakeholders is a common way of dealing with them. In this paper, all stakeholders are classified into three categories: national; regional; and local. Table 1 presents a list of all stakeholders, their categories, and abbreviations.

2.3. Data collection

After identifying the study area, and the main stakeholders, the required data was gathered through interviews with experts to analyse the stakeholders and their social network. At least two delegates of each stakeholder and academic scholars were selected as experts for interviews. The number of experts who completely answered the questions are variable for different stakeholders; however, more than two delegates shared their views on behalf of the consumers.

An identical questionnaire with three main parts was designed. In the first part, the interviewees were asked about the roles, power of their influence on the system, interests in the current condition of the system, level of satisfaction, and access to information of all stakeholders, including the ones they were representing. Also, they answered the questions about the responsibility of their party in the current condition of the system. For each question, the respondents used a Likert scale [44] between 1 and 5 to express their opinion. The details were shown in Table 2.

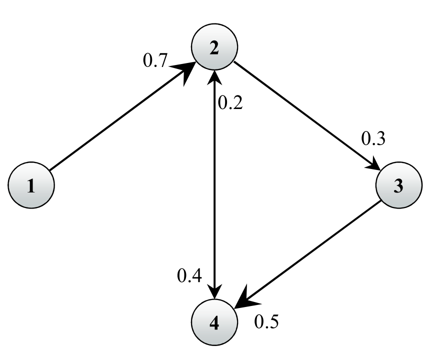
In the second part, experts were questioned to evaluate the relationship between the actors having organisational relationships with their institution. As indicated in Table 2, they could give an integer score between 0 and 5 (for cooperative collaboration) or between 0 and -5 (for non-cooperative collaborations). These data from the first and second parts were used in SA and SNA, respectively.

In the third part, the experts were asked in detail about the role of their party in energy management in WDN, their priorities, and the essential barriers for optimal energy management in the case study WDN.

The first and second parts of the interview could be determined as structured, while the third part was non-structured. In total twenty people were interviewed.

Table 3
Power, interest, access to information, and satisfaction of current condition values for all stakeholders.

Stakeholder abbreviation	Power	Interest	access to information	satisfaction
P&B	4.18	2.04	2.00	4.00
Parl	3.82	1.88	2.00	2.50
MoE	4.23	2.40	4.00	5.00
WWC	4.27	4.20	5.00	5.00
RWBC	3.09	3.64	3.00	4.00
REC	3.00	2.82	1.00	3.00
EPA	2.36	2.45	1.00	2.50
HO	1.91	1.73	2.00	4.00
BFI	2.18	1.45	1.00	2.00
Gov	2.27	2.64	3.00	3.50
CC	3.18	3.18	3.50	4.00
Mun	3.09	2.91	3.50	3.00
FO	1.55	1.64	3.00	4.00
Lan	1.82	1.82	2.50	4.00
Cntr	2.36	2.64	3.50	3.00
Cnsl	2.36	2.55	4.00	3.00
NGO	2.00	2.09	1.00	2.00
Cnsm	1.80	4.30	1.00	3.00
Average	2.75	2.58	2.56	3.42



(a)

$$\begin{array}{c|cccc|c} & 1 & 2 & 3 & 4 & \text{out-degree centrality} \\ \hline 1 & 0 & 0.7 & 0 & 0 & 0.7 \\ 2 & 0 & 0 & 0.3 & 0.4 & 0.7 \\ 3 & 0 & 0 & 0 & 0.5 & 0.5 \\ 4 & 0 & 0.2 & 0 & 0 & 0.2 \\ \hline \text{in-degree centrality} & 0 & 0.9 & 0.3 & 0.9 & \end{array}$$

(b)

Fig. 4. (a) A schematic diagram of the stakeholders' network; and (b) adjacency matrix, in-degree and out-degree centralities for each node.

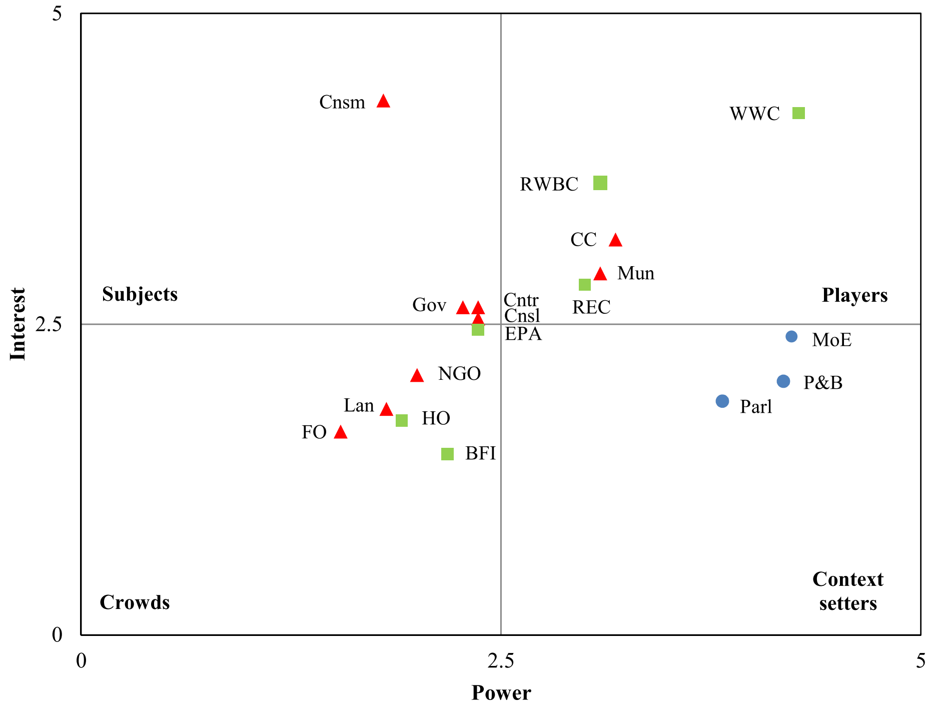


Fig. 5. Power-interest grid for the stakeholders in this study.

2.4. Application of SA

Once the data was gathered from interviewees, SA carried out on the data. Representatives of the stakeholders (experts) were asked to express their thoughts about the power of influence on the WDN and their interests in this regard. The stakeholders' powers and interests were determined by averaging the experts' answers. Depicting a power-interest grid, all stakeholders could be categorised into four classes, given their powers and interests: 1) Players: stakeholders with high power and high interest; 2) Subjects: stakeholders with low power and high interest; 3) Context-setters: stakeholders with high power and low interest; and 4) Crowds: stakeholders with low power and low interest [45].

In addition, the answers of each stakeholder about their access to information and satisfaction with the current status of the system were analysed and compared.

2.5. Application of SNA

As indicated in the Data Collection Section, after performing the interviews, the data were translated to the centrality metrics to be analysed. UCINET software was used to analyse the social network of stakeholders [46]; which is capable of assessing the relationships within the network and computing indicators such as centralities. The absolute quantities of the links between stakeholders were taken into consideration together with the out-degree, in-degree, between-ness, and beta centrality values. The following equations can be used to compute in-degree and out-degree centralities for each stakeholder [47]:

$$IC_i = \sum_{j=1}^{N} R_{ji} \tag{1}$$

$$OC_i = \sum_{j=1}^{N} R_{ij} \tag{2}$$

where; IC_i and OC_i represent In-degree Centrality and Out-degree Centrality of the i-th stakeholder, respectively. N is the number of stakeholders; and R_{ij} is the element of the i-th row and the j-th column of the adjacency $N \times N$ matrix. The adjacency matrix is a matrix whose elements represent the intensity of connections existing between various network vertices [48]. It should be noted that IC_i sums the intensity of the connections from other stakeholders to i-th stakeholder (in-degree), while OC_i sums the intensity of the connections from i-th stakeholder to other stakeholders (out-degree). Fig. 4 presents a simple weighted and directed network, where the intensities of the relationships are shown on the arrows connecting the nodes. Adjacency matrix, in-degree and out-degree centralities are calculated in Fig. (4b).

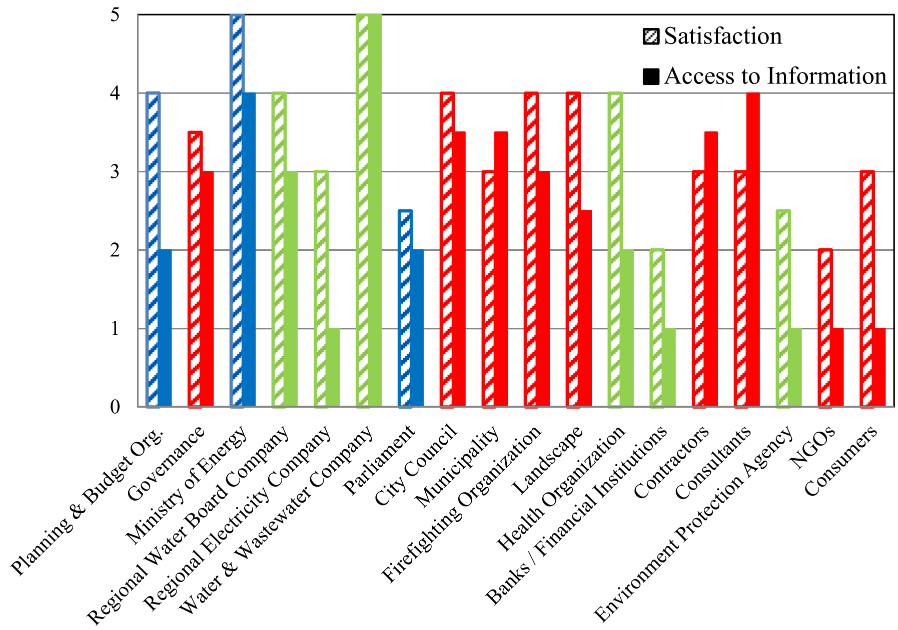
On the other hand, the value of IC_i in equation (1) reflects both the quantity and quality of formal or institutional relationships that all stakeholders have with the i-th stakeholder. On the other side, greater values of OC_i suggest that the i-th stakeholder has more solid linkages with more stakeholders (Eq. (2)). The number of stakeholders designated by each stakeholder as organisations with whom it has formal or institutional relationships, as well as their quality, are specifically indicated by the value of OC_i. A stakeholder with a higher out-degree centrality thus has simple access to other stakeholders and is likely to have an influence on them.

In addition, for both positive (cooperative) and negative (non-cooperative) links, out-degree and in-degree centralities were investigated individually. Based on equations (1) and (2), it is required to take into account the number of matrices' components without their signs when computing in-degree and out-degree centralities for either positive or negative networks.

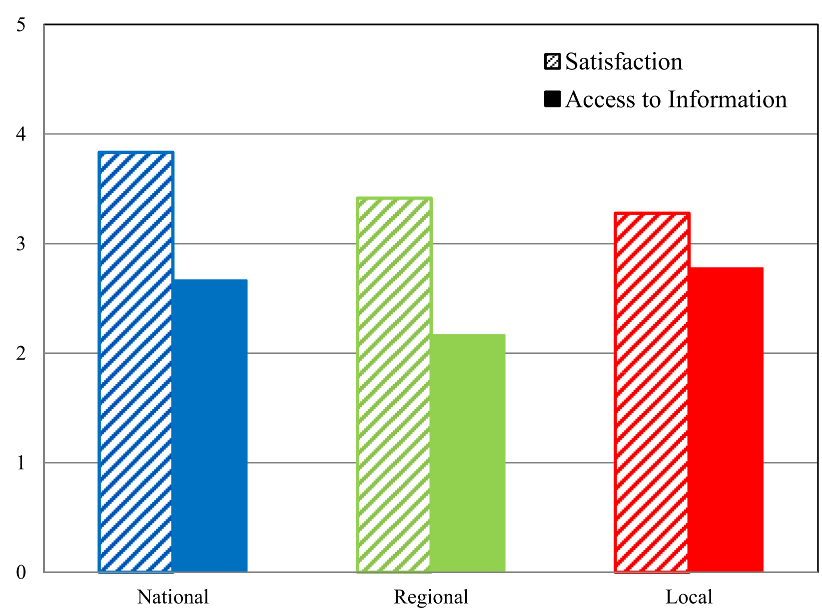
Between-ness centrality of a vertex can be calculated by Eq. (3), while i, j and k are three distinct vertices in the network [47].

$$B_i = \sum_{i \neq j \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}} \tag{3}$$

where, σ_{jk} is equal to the number of geodesic paths between vertices j and k; and σ_{jk} (i) is equal to the number of geodesic paths between vertices j and k and passing through vertex i. It should be noted that the geodesic path between two vertices in a network means a path containing the least number of nodes between those two vertices. It is important to point out that this centrality can be determined either in



(a)



(b)

Fig. 6. Values of metrics for satisfaction and access to information for: (a) individual stakeholders; and (b) each group of stakeholders.

directed/undirected or binary/weighted networks. Directed networks are those in which interactions have a definite direction but are not always bi-directional. Additionally, in binary networks, the intensities of relationships are not considered, such that two nodes either have a relationship or not. In contrary in weighted networks, each relationship has certain intensity (weight). A vertex in a social network may play a stronger intermediate role if its between-ness degree centrality is higher [49].

In addition to the centrality of a vertex, an index called beta centrality or Bonacic power also takes the centralities of nearby vertices into account. The formula used to compute this index is as follows (Bonachich, 1987):

$$C_i = \sum_{j=1}^{N} R_{ij} \times \left(\alpha + \beta \times C_j\right) \tag{4}$$

In equation (4), C_i and C_j are Beta Centrality values of i-th and j-th vertex, respectively; α is a normalization parameter chosen by software;

Table 4
Social network assessment metrics in case study WDN management system.

Stakeholders	Absolute amounts				Only positive amounts		Only negative amounts	
	Out-degree	In-degree	Between-ness	Beta	Out-degree	In-degree	Out-degree	In-degree
P&B	26.00	26.00	0.26	28,369.89	25.67	25.67	0.33	0.33
Parl	26.00	26.00	1.16	25,801.39	26.00	26.00	0.00	0.00
MoE	32.33	33.00	0.79	33,694.46	32.00	32.67	0.33	0.33
WWC	40.33	40.33	1.71	38,355.87	40.33	40.33	0.00	0.00
RWBC	27.00	27.67	1.71	28,484.12	25.67	26.33	1.33	1.33
REC	20.67	19.33	0.25	20,442.64	19.00	17.67	1.67	1.67
EPA	24.00	24.00	1.71	25,502.48	24.00	24.00	0.00	0.00
HO	10.00	10.00	0.00	10,860.97	6.00	6.00	4.00	4.00
BFI	24.67	24.67	1.71	25,370.22	23.00	23.00	1.67	1.67
Gov	16.00	16.00	0.79	16,972.79	15.00	15.00	1.00	1.00
CC	38.33	37.67	1.71	33,527.24	38.33	37.67	0.00	0.00
Mun	36.33	36.33	1.71	31,846.98	36.33	36.33	0.00	0.00
FO	14.33	15.00	0.44	17,010.37	12.67	13.33	1.67	1.67
Lan	13.33	13.33	0.12	14,638.81	11.33	11.33	2.00	2.00
Cntr	22.67	22.67	1.71	23,855.26	21.67	21.67	1.00	1.00
Cnsl	22.67	22.67	1.71	23,779.33	21.67	21.67	1.00	1.00
NGO	22.33	22.33	0.00	24,062.08	22.33	22.33	0.00	0.00
Cnsm	18.33	18.33	1.71	18,182.40	13.00	13.00	5.33	5.33

and N and R_{ij} are the same as defined in Eqs. (1) and (2).

β is a coefficient that establishes how much each vertex's centrality depends on the centralities of its surrounding vertices. The vertex's centrality will rise if the value of this numerical parameter is positive, and the neighbourhood contains more central vertices. If this value is supposed to be negative, the adjacency with non-central vertices raises the vertex's centrality. The absolute amount of β should be less than the inverse of the biggest eigenvalue of the adjacency matrix of the network.

$$\beta = \frac{0.995}{Max\ Eigenvalue} \tag{5}$$

where, *Max Eigenvalue* is the largest eigenvalue of the network's adjacency matrix.

In this study, using UCINET software eight indicators were computed for each stakeholder; once, in-degree, out-degree, between-ness, and Beta centralities were calculated for absolute amounts of the relationships, then in-degree and out-degree centralities were determined only considering the positive and negative relationships, which are measures for indicating the centrality of each stakeholder in cooperative and non-cooperative relationships. Calculating the values of the abovementioned metrics, the social network of the stakeholders was illustrated by using NETDRAW software [50].

2.6. Comparison of SA and SNA metrics

In previous studies, SA and SNA were combined for certain water resources management systems [19,51,52]. In this paper, the results of SA (values of power, interest, satisfaction, and access to information) were compared to the values of eight metrics resulting from SNA, and their correlation was calculated. The correlation coefficient is calculated through Eq. (6):

$$R(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \tag{6}$$

where, $R(X,Y)$ is the correlation coefficient of datasets X and Y; $\bar{x}$ and $\bar{y}$ are the means of X and Y, respectively. The potential high correlation between the two metrics of SA and SNA shows that each of them can be used interchangeably.

3. Results and discussion

The abovementioned methodology was employed to analyse the data and present the results. In the stakeholders' analysis, the results of the interviews were used to categorise them into three groups, according to their circle of influence. The stakeholders who have the authority to implement their plans in the entire country are *National* stakeholders. The ones who are responsible to act in a province (or state) are called *Regional* stakeholders, and those who can only play a role in a district smaller than a province (e.g., a city or a town) are the *Local* stakeholders. In this paper, 3, 6, and 9 stakeholders were categorised as national, regional, and local, respectively (Table 1). In this paper, national, regional, and local stakeholders are shown in blue, green, and red colours, respectively.

The gathered data about the stakeholders was used to analyse their motivation for collaborating in implementing energy recovery projects in WDNs. Based on the interviews, the power and the interest of each stakeholder in energy recovery projects in WDNs have been computed by averaging the answers of each interviewee (Table 3). The power-interest grid is illustrated in Fig. 5 to better understand the results. In this graph, the national stakeholders; MoE, P&B, and Parl, were categorised as contest-setters. This result is reasonable, because they have high power to influence the case study WDN, but low interest in it. Among the regional stakeholders, WWC, RWBC, and REC were recognised as players, while EPA, HO, and BFI were considered as a crowd. As the study is about energy management in a WDN, it was predictable that the WWC, RWBC, and REC were determined as the most central stakeholders. Local stakeholders (except CC and Mun) are classified as subjects or crowds, proving their low power in influencing the decisions. The main subjects of the network are the consumers (Cnsm), due to their high interest and low power in energy management in WDNs.

The values of metrics for access to information and satisfaction with the current state were achieved only from the answers of each stakeholder's delegates (Table 3). The values vary between 1 and 5; in a way that the more values indicate the more access to information and satisfaction from energy recovery projects in WDNs. The results are presented for each stakeholder in Fig. 6, in which most of the stakeholders are satisfied with the current status of the WDN and the mean of the satisfaction values is more than the average (2.5). WWC and MoE are the most satisfied and BFI and NGO are the least satisfied ones (Fig. (6a)). Also, it is worth noting that the NGOs are less satisfied than the consumers, which proves their propensity to claim. Fig. (6b) suggests that the average satisfaction of all three groups are close to each other, with a little higher amount for the national.

Among the studied stakeholders, WWC and MoE have the highest access to information, because they are the main operators of the WDN. Each project related to WDN should be decided by these two stakeholders. Moreover, REC, BFI, EPA, NGO, and Cnsm have the lowest

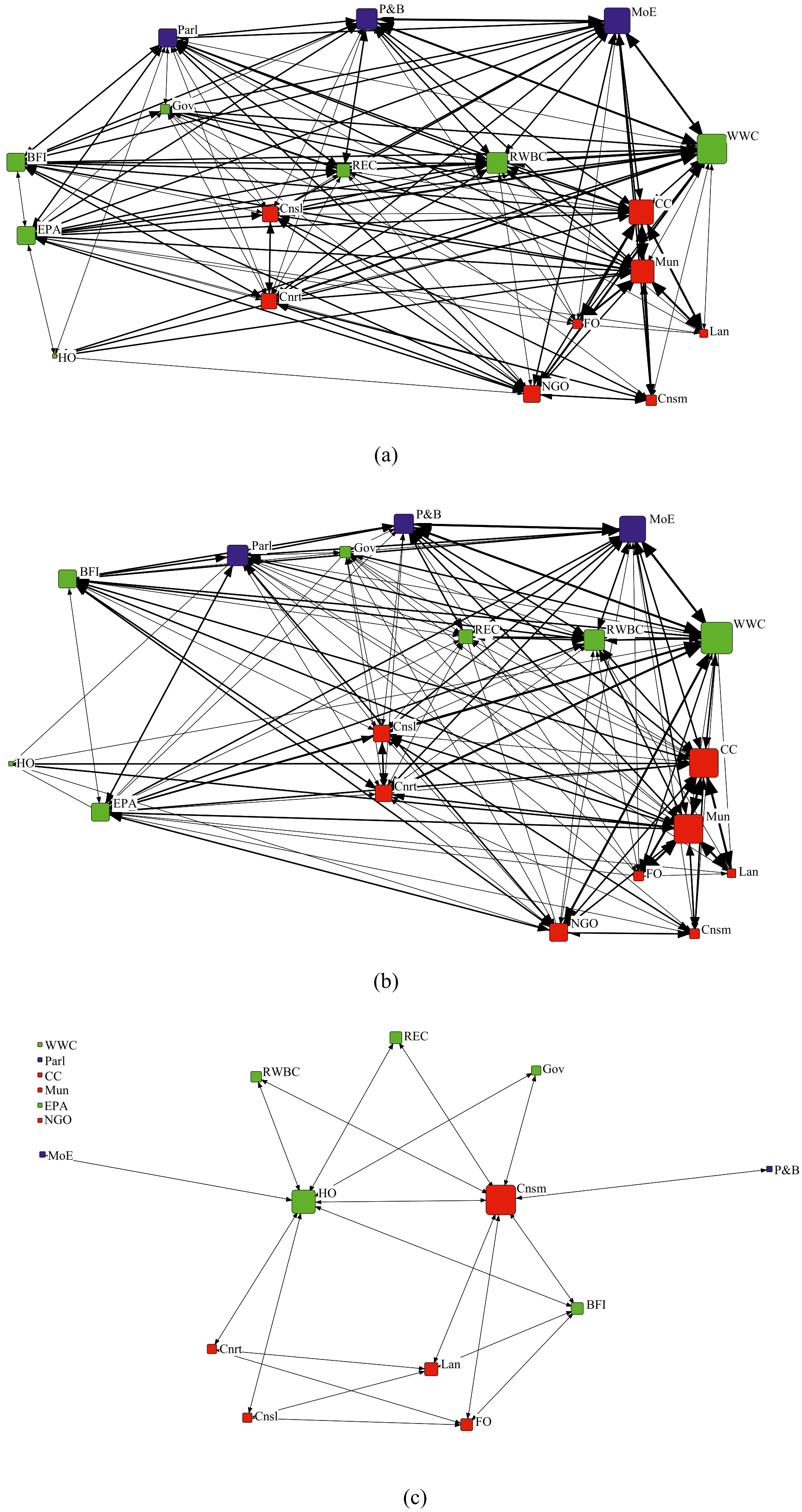


Fig. 7. Social network of stakeholders in energy recovery programmes in the case study WDN; (a) Entire social network; (b) only cooperative relationships; and (c) only non-cooperative relationships.

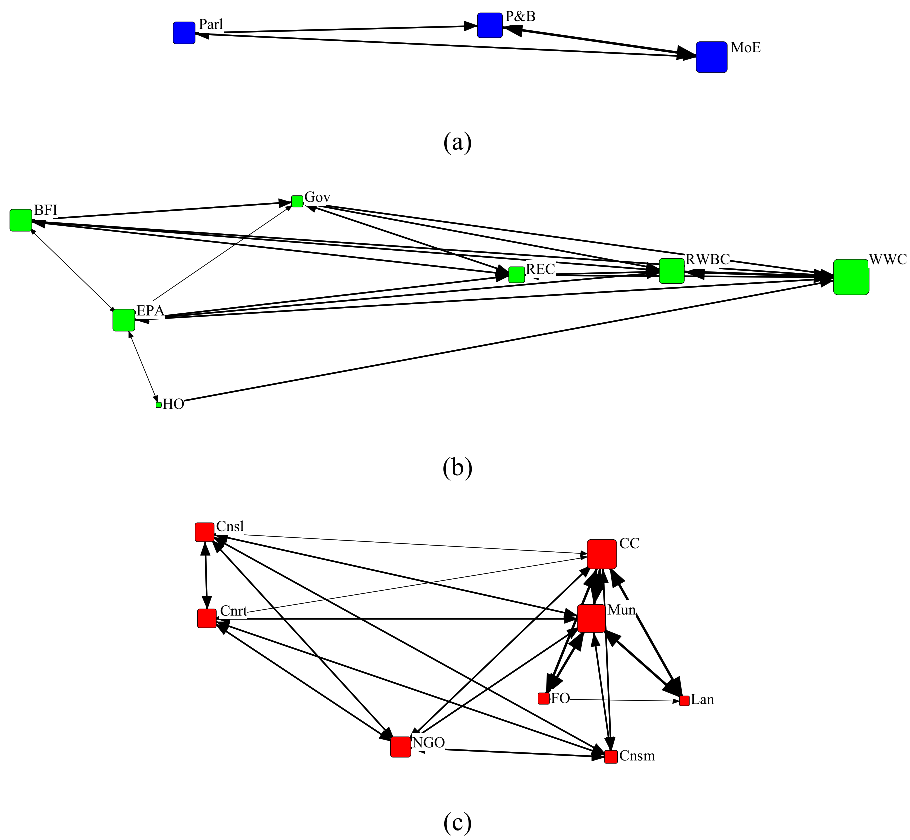


Fig. 8. Inter-organisational ties of stakeholders for the groups of (a) national; (b) regional; and (c) local; stakeholders.

Table 5
Average metrics of SNA for stakeholder groups in case study WDN.

Stakeholders' group	Absolute amounts				Only positive amounts		Only negative amounts	
	Out-degree	In-degree	Between-ness	Beta	Out-degree	In-degree	Out-degree	In-degree
National	28.11	28.33	0.74	29,288.58	27.89	28.11	0.22	0.22
Regional	24.44	24.33	1.18	24,836.05	23.00	22.89	1.44	1.44
Local	22.70	22.70	1.10	22,652.81	21.37	21.37	1.33	1.33

Table 6
Coefficient of correlation between results of SA and results of SNA.

SA results	Absolute amounts				Only positive amounts		Only negative amounts	
	Out-degree	In-degree	Between-ness	Beta	Out-degree	In-degree	Out-degree	In-degree
Power	0.751	0.750	0.162	**0.790**	0.759	0.758	−0.566	−0.566
Interest	0.471	0.465	**0.550**	0.417	0.402	0.397	0.122	0.122
Satisfaction	0.224	0.240	−0.138	**0.242**	0.201	0.215	−0.002	−0.002
Access to Information	0.495	0.512	0.314	0.488	0.499	**0.515**	−0.365	−0.365

access to information. It should be undesirable for REC to have such low access to information, particularly about energy management in the WDN. It is expected that enhancing the relationship between WWC and REC, as well as providing REC with more access to information improves the energy management in WDN. Nonetheless, the national and local stakeholders have the same average value of access to information, slightly higher than that of regionals.

As mentioned in the Methodology Section, SNA includes how stakeholders are connected and their inter-agent behaviour. Results include metrics for each stakeholder and also illustrate the social network after the SNA.

Different evaluated indicators for the social network of the case study WDN are presented in Table 4. Each stakeholder could have a relationship of 0–5 with the other 17 stakeholders, so the minimum value for in-degree and out-degree centralities for each stakeholder is zero (i.e. no connection to any other stakeholder), and the maximum value of these metrics is $17 \times 5 = 85$ (i.e. full connection with all other 17 stakeholders). Between-ness and beta centralities may have various change intervals, depending on how the network is structured. Moreover, in-degree and out-degree centralities were determined in three states: considering all relationships, only considering the positive (cooperative) relationships, and only considering the negative (non-cooperative relationships). Also, the graphical representation of the stakeholders' network in different states is shown in Fig. 7. While Fig. (7a) presents the entire network of the stakeholders, cooperative and non-cooperative relationships are demonstrated in Figs. (7b) and

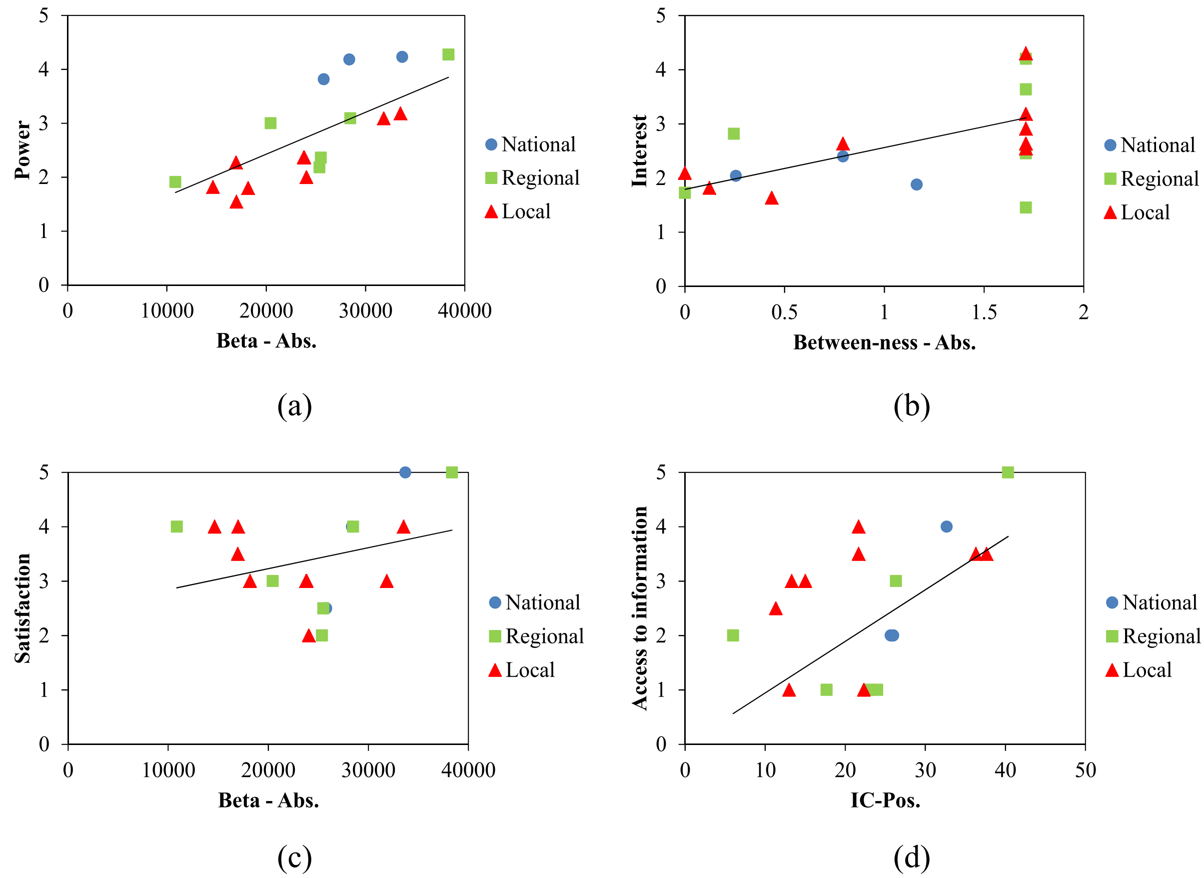


Fig. 9. Relationship between SA metrics and SNA metrics for the highest correlation coefficients: (a) power vs. beta (absolute values); (b) interest vs. between-ness (absolute values); (c) satisfaction vs. beta (absolute values); (d) access to information vs. in-degree (positive values).

(7c), respectively. While Fig. 3 represents basic interactions between stakeholders, Fig. 7 depicts the entire stakeholders' network in more details. Based on Fig. (7c), WWC, Parl, CC, Mun, EPA, and NGO have no non-cooperative relationship with others. The line thickness relatively shows the strength of the links. Blue, green, and red hues, represent the national, regional, and local stakeholders, respectively. The node sizes reflect beta centrality in Fig. (7a), and in-degree centrality in Figs. (7b) and (7c). In Fig. (7c), Cons has the highest in-degree centrality in non-cooperative relationships, which proves its vulnerability. The high density of the network can be inferred from looking at the visual representation of the social network. In this sense, all stakeholders within the network have organisational relationships with one another, either directly or, at least, indirectly. The highest amount of in-degree, out-degree, between-ness, and beta centrality for the absolute values of relationships are held by the WWC, which shows the high importance of this agent among the WDN management. At the national level, MoE has the highest centrality, even more than P&B and Parl, which is because of the ministry's specialised mission in water and energy administration. However, REC exhibits *unexpectedly* low centrality in the network, which might be raised by enhancing the relationship between WWC and REC which benefits both organisations' management strategies. The WWC will benefit from this connection by reducing energy costs, while REC will profit in terms of power demand response.

Despite the fact that consumers are crucial in a network, it can be seen that their relevance is modest and their relation with WWC stays at a low level. This might be a result of WWC's non-private character, which funds its activities mainly through government finances, not the consumers' bills.

The relationships between the national, regional, and local groups of stakeholders are displayed in Fig. 8. In this figure, the size of the nodes represents the beta centrality, while the thickness of the lines shows the strength of the relationships. MoE, WWC, and CC are the most important stakeholders at national, regional, and local levels, respectively. Divided by stakeholders' groups, the average metrics of SNA are shown in Table 5. The national stakeholders have the largest in-degree, out-degree, and beta centrality, whereas the regional stakeholders have the highest between-ness degree of centralities.

Having done the SA and SNA, the results were combined and compared to find the relationships. Table 6 presents the correlation coefficient of the four metrics of SA against eight metrics of SNA. In this table, the maximum correlation coefficient for each SA metric is shown in bold. Although the correlation is not high for all metrics, it can be seen that power, interest, satisfaction, and access to information have the highest correlation with beta, between-ness, beta, and in-degree (for positive amounts) centralities, respectively.

As mentioned before, the higher beta centrality indicates a stronger relationship between the stakeholder and more central stakeholders. In this context, it is predictable that the beta centrality has a high correlation with the power index. Moreover, between-ness centrality specifies the stronger intermediate role of a stakeholder. This is why this metric has a high correlation with the interest metric, achieved from SA. Access to information values has well correlations with in-degree and out-degree centralities, proving the fact that more central stakeholders have more access to information.

Fig. 9 illustrates the relationship between SA metrics and SNA metrics for the highest correlation coefficients. According to this analysis, beta centrality and between-ness centrality may be utilised to identify the power and interest of stakeholders.

4. Conclusion

The network of stakeholders impacting energy management in WDNs is examined in this paper. Interviews have been done with water experts and representatives of stakeholders to identify the main agents. Applying SA, the characters of each stakeholder, e.g. power, interest, access to information, and satisfaction were investigated. Also, through SNA, the stakeholders' positions within the network were determined by using in-degree, out-degree, between-ness, and beta centrality metrics.

The water and wastewater company (WWC) has the highest in-degree, out-degree, between-ness, and beta centrality, demonstrating the high importance of this agent in the energy management of a WDN. Comparing SA and SNA results reveal some level of correlation between SA and SNA metrics, i.e. some SA metrics can be approximated by SNA metrics.

Although the SA and SNA approaches were frequently employed in water resources and ecosystems management studies, they were never utilised in companion to analyse the stakeholders within a WDN. SA and SNA analysis is essential for a profound understanding of the stakeholders and their connections, due to the significance of urban WDN projects and the potential of conflicts in stakeholders' relationships. In urban projects, sometimes powerful stakeholders seek their (conflicting) utilities, which might delay the project. For example, when it comes to generating renewable energy from water pipelines, water utility companies may not consider energy production as a part of their mission. The electricity companies are keen about these projects, but do not have access to the WDN detailed information to estimate the electricity generation capacity. Health organisations are worried about the water quality degradation, when the water passes through the turbines. Financing institutes would be engaged only when they are confident about the return on investment. In such cases, SA and SNA clarify the position and weight of each stakeholder in the project. These analyses could determine the stakeholders with high power to impact on the project, high interest in benefits from the project, a pivotal role in the social network of stakeholders, etc.

As this research has been carried out in a case study WDN, the results are limited to the investigated case study, however, the same methodology is applicable to any other WDNs. Depending on the governing system of the WDN, the influencing stakeholders can be slightly different from what has been studied here, nevertheless, in most of the cases the same results are expected. For the future studies, agent-based analysis of the stakeholders, particularly the consumers, can be a suitable topic. Optimal selection of the hydropower generators, i.e. their number, type, locations, work time, etc. to maximise the collaboration of the stakeholders and minimise their conflict of interest is another interesting subject for the further research.

The results of this research help the decision makers to rank the scenarios for implementing the energy harvesting equipment in the WDNs and find the scenarios with the highest level of agreement among the stakeholders.

Credit author statement

Milad Latifi: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Visualization, Funding acquisition.; **Reza Kerachian:** Conceptualization, Methodology, Writing - Original Draft, Supervision, Funding acquisition.; **Ramiz Beig Zali:** Writing - Original Draft, Visualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Milad Latifi reports financial support was provided by Iran National Science Foundation. Reza Kerachian reports financial support was provided by Iran National Science Foundation.

Data availability

Data will be made available on request.

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Nomenclature

B_i	Between-ness centrality of the i-th stakeholder
BFI	Banks/Financial institutions
C_i	Beta Centrality values of the i-th stakeholder
CC	City Council
Cnsl	Consulting engineers
Cnsm	Consumers
Cntr	Contractors
EPA	Environment Protection Agency
FO	Firefighting Organisation
Gov	Governorates
HO	Health Organisation
IC_i	In-degree Centrality of the i-th stakeholder
Lan	Landscape
MoE	Ministry of Energy
Mun	Municipality
N	number of stakeholders
NGO	Non-governmental Organisations
OC_i	Out-degree Centrality of the i-th stakeholder
P&B	Planning and Budget Organisation
Parl	Parliament
R_{ij}	element of the i-th row and the j-th column of the adjacency $N \times N$ matrix
$R(X, Y)$	correlation coefficient of datasets X and Y
REC	Regional Electricity Company

RWBC	Regional Water Board Companies
SA	Stakeholder Analysis
SNA	Social Network Analysis
TPWW	Tehran Province Water and Wastewater Company
WDN	water distribution networks
WWC	Water and Wastewater Companies
$\overline{x}$	mean of dataset X
$\overline{y}$	mean of dataset Y
α	normalization parameter
β	coefficient
σ_{jk}	number of geodesic paths between vertices j and k
σ_{jk} (i)	number of geodesic paths between vertices j and k and passing through vertex i

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