Food Security Goal Analysis using Multi-Objective Reasoning: Treated Sewage Water Case Study

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***Abstract*—Food security, the ability to access safe, sufficient, and healthy food, is fundamental for governments to ensure societies' healthy lifestyles and the well-being of all citizens. Food sovereignty is one of the vital requirements to achieve food security at a national level. Societies have introduced different mechanisms to increase their national food production. The use of treated sewage effluent in irrigated agriculture sector is one of the main adaptation mechanisms. Governments encourage the use of this new source by providing technical and financial support and subsidizing the price of water. However, farmers are hesitant to benefit from the subsidies as they do not have access to the required information or they come across conflicting information from different resources. These barriers prevent many farmers from using treated sewage effluent on their farms, which leads to either using desalinated water, that is expensive and energy intensive, or decreasing agriculture activities, which subsequently decrease local crops productivity and thus increase country reliance on food imports.**

This paper defines information requirements for farmers, based on a case study of farmers' use of treated sewage effluent in irrigated agriculture in Abu Dhabi. The multi-objective reasoning with constrained goal models was used to define constraints and optimization goals over multiple objective functions, refinements and their numerical contributes. Several interviews were conducted, with those who have used treated sewage effluents for irrigation, to validate the generated model, and help in defining how farmers can also contribute to defining information needs to maximize the use of treated sewage effluent in agriculture.

***Index Terms*—Goal-oriented requirements engineering; sustainability; food security; social acceptance**

I. Introduction

Food security was introduced in 1974 at the World Food Conference with emphasis on food supply. It was further developed over time to cover several aspects including food supply, food availability, and affordability. The latest and most commonly used definition of food security was introduced by the State of Food Insecurity in 2001 as *"a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"* [1]. The four main components of food security as identified by the United Nations Food and Agriculture Organization are availability, access, use, and stability [2].

Under the current climate change conditions, food availability and stability become major concerns for nations and individuals. In arid and semi-arid regions, like the UAE, limited water resources, high population growth, harsh weather conditions and climate change have contributed to limit the options to increase food production and put the farmers and the governments under high pressure to achieve food security [3], [4]. The use of non-conventional water resources, e.g., treated municipal wastewater, also known as treated sewage effluent (TSE), was introduced as a key adaptation measurement to climate change and drought. Since then, the use of TSE to overcome the limited water resources in irrigated agriculture, and to minimize the impact of wastewater disposal on the environment was successfully demonstrated in several countries [5], [6]. However, the adoption of this measurement at large scale and in many countries, including the UAE, is still facing several constraints including public and farmers acceptance [7], [8], health risks [9], [10], and potential environmental impacts [11], [12].

It is important that farmers understand the added value of using TSE in irrigated agriculture. In the case of UAE, wastewater is being treated to tertiary level. Which means that the quality of water produced is suitable for direct use in irrigated agriculture. The UAE treats around 265 MCM/year (around 39% of the produced wastewater)[3] out of which 159 MCM (around 60%) is reused per year [3]. This figure shows that the use of TSE in irrigated agriculture is still limited despite the Government technical and financial support to help farmers in using this non-conventional water resource. This might be related to the limited knowledge on how to use TSE in a safe manner, the type of crops to produce in terms of its suitability to the climate (drought resilience and salt-tolerant), and the TSE suitability to agriculture.

Researchers and technical teams look always for the best technology to enhance the quality and quantity of TSE, and how to eliminate the environmental impacts of using the effluent in irrigated agriculture [13]. However, limited studies focus on farmers' knowledge requirements to encourage the use of TSE [14], [15].

Engaging farmer is a critical element in encouraging broader use of TSE in irrigated agriculture. A good example to be investigated is that of Abu Dhabi. In 2012/2013, Environment Agency-Abu Dhabi launched an innovative program, with the objective of introducing the TSE in irrigated agriculture to increase crops production and minimize the use of groundwater in irrigated agriculture. The project managed to treat almost 27 million liters of water a day to a standard good enough for agricultural use. It was used on 220 farms across the emirate [16].

This paper intends to define the goals and requirements for maximizing farmers' use of TSE. It analyzes and reports the initial results of Abu Dhabi's experimental study by applying the CGM and its reasoning tool CGM-Tool introduced in [17]. The Constraints Goal Model (CGM) which considers multi-objectives while helps in maximizing the benefits, and the adoption of stakeholders' participatory approach, offer a substantial potential to not only achieve the required level of TSE use in irrigated agriculture but also in achieving end-user engagement among other preferential goals.

The advantage of using this model is to enable users refining goals, expressing preferences between the goals and their refinements, as well as associating numerical attributes to goals and their refinements. This helps in optimizing goals over multiple objective functions and their numerical attributes and in defining the constraints as well as the motivation of farmers (i.e. maximize preferences) who chose to use TSE.

The main research questions will focus of eliciting farmers' requirements for using TSE, especially their information needs:

RQ1. What encourages farmers to use TSE in irrigated agriculture?

RQ2. What information have farmers received, or would like to receive, to enable them to take an informed decision? What other information should be shared?

Interviews with five farmers who accepted to use TSE in their farms were conducted. The aim of the interviews was to validate the model and understand the type of information farmers have received, and what kind of information farmers have been looking for in order to define the minimum required information and knowledge.

II. Background and Related Work

Climate change imposes threats to human's ability to achieve sustainable development. It further threatens ecosystems and natural resources sustainability. Climate change has generated different climate-induced disasters (e.g., drought, flash floods, heat-waves, and sea-level rise). It is estimated that climate change will contribute to 250,000 deaths every year between 2030 and 2050 [18]. It will also decrease the amount of available water resources in some regions including the Middle East by more than 10% [19]. As of 2006, around 11% of the total world population lived under chronic water scarcity threshold as defined by the UN, which is 1000 m^3/capita.year; moreover, this percentage is projected to increase to 38% by the year 2025 [20]. However, there are huge disparities between regions and countries. According to the IPCC report, by the year 2025 the Middle East region will be suffering the most and reaching the 100 m^3/capita.year [21]. This is the minimum survival level that the United Arab Emirates has already reached in 2006, along with Kuwait, Gaza Strip, Qatar, Saudi Arabia, Maldives, and the Bahamas.

In response to this global, regional, and national water stresses, mitigation, and adaptation measures were introduced at all levels to cope with climate change impacts and to mitigate its occurrence. As agriculture sector consumes around 70%-76% of the total water [20], [22], one of the main introduced mitigation and adaption measures to help cope with the water stresses is the reuse of TSE in irrigated agriculture [20]. It is estimated that around 200 million farmers, at the global level, farming at 20 million ha, use treated, or partially treated, or untreated wastewater [22].

Farmers are the key actors in the agriculture sector. The use of TSE in irrigated agriculture depends on farmers' understanding and acceptance of the idea. However, if farmers are not fully aware of the benefits and constraints of using TSE in irrigated agriculture, then the use of this resource can prove inadequate in many ways, including limited use of TSE by farmers [15], wasting a valuable source that can increase the vegetation cover while adapting to climate change [20], [14], and functional requirements for the TSE not being provided to farmers who might be unhappy with the use of TSE in their farms [14].

A study by Mizyed [14] in arid and semi-arid areas identified the main challenges for TSE use; those include the limited knowledge available and shared with farmers concerning the socio-economic, and the legal and political considerations of using the treated effluent. Furthermore, he confirmed that farmers who received technical training, information and knowledge on the proper use of TSE were happy and reported a high level of satisfaction of using TSE in their farms.

A. Goal-Oriented Requirement Engineering

The literature in the irrigation field area suggests that knowledge of constraints and opportunities associated with the use of TSE in irrigated agriculture is very crucial to guide policy formulation and provide a better understanding of the limitations as well as the trade-off, to inform better decisions making process [20]. Van Lamsweerde [23] indicates that systems could fail if their requirements are not adequately identified and analyzed. Therefore, knowledge is very crucial to encourage farmers using TSE in their farms to ensure achieving food security and release pressure on water resources.

The stakeholders of the reuse of TSE need to obtain the minimum knowledge requirements to enable them to take informed decisions. However, no specific efforts have been made to define the needed requirements. Sharing of unnecessary information and requirements may jeopardize stakeholders' ability to take right decisions as this may lead to confusion, and unnecessary investments in money, time, and efforts [24].

Requirement Engineering (RE) could be used to define the minimum requirements and information needs to maximize the use of TSE in irrigated agriculture. RE facilitates elicitation, evaluation, specifications, and analyses processes, as well as the evolution of the objectives of a system, its functionality, and the constraints a system might face [23], [25].

RE helps in examining and understanding the relationships among the system's social actors [26]. It leads to the development of the conceptual framework for modeling and analyzing processes that involve multiple stakeholders as well as fulfilling the intention [27].

RE defines the needs of a system and its users [24], [26]. The relationships between actors in the domain usually lead to intentionality. This can be better described using the Goal-Oriented Requirement Engineering (GORE) approach, which involves the understanding of why a system function is required, and how those functions can be implemented [23]. Furthermore, there are several advantages for using GORE approach; those include: it allows for scalability of the application domain based on assumptions, provides a rationale for requirements, provides traceability, and provides assignment of responsibilities [25].

GORE approach uses goals for all RE processes: eliciting, evaluation, negotiation, structuring, documentation, analysis, and evolution [23], [25], [26]. Goals are statements of intent that the system should satisfy through the collaboration of its agents [23], [25], [28], while agents are the players who define the scope of the system [23], [26], [27].

During the past two decades, several GORE modeling techniques have been established and advanced. The most popular methods among those are Keep All Objects Satisfied (KAOS) [23], [29], [30], i* [26], NRF Framework [25], TROPOS [27], [31], and GRL [28]. However, those modeling techniques do not have clear means to track or respond to continuous changes in real systems, therefore, lack of optimization goals and scalable reasoning facilities are the common limitation among GORE methods.

In response to these common limitations, Nguyen *et al.* [17] have proposes a new expressive extended goal-oriented modeling language, named constrained goal model (CGM). In addition, a set of automated reasoning functionality over this model was developed in a tool named CGM-Tool. The newly developed model, CGM, has the following advantages as explained in [17]:

- *Goals and goals refinements*: CGM makes explicit the notion of goal refinement.
- *Domain*: the model provides an explicit representation of domain assumption, allows for expressing preferences between goals and refinements.
- *Constraints*: the model associates numerical attributes to goals and refinements for defining constraints.
- *Optimization*: the model defines optimization goals over multiple objective functions, refinements, and their numerical attributes.

III. Research Method

Engaging farmers in defining goals and requirements could be a critical element in encouraging and maximizing TSE use in irrigated agriculture. Applying the newly developed CGM model and tool on the use of TSE in irrigated agriculture helps in investigating the usability and replicability of the new model and its associated tool in a different domain. The advantage of using this model, as stated by [17] is to enable users refining goals, expressing preferences between the goals and their refinements, as well as associating numerical attributes to goals and their refinements. This helps in optimizing goals over multiple objective functions and their numerical attributes.

A. Research Questions

The main research questions focus of eliciting farmers' requirements to maximize TSE use in irrigated agriculture, especially their information needs.

RQ1. What encourages farmers to use TSE in irrigated agriculture?

To define the requirements, it is crucial to understand what encourages farmers to use TSE in irrigated agriculture (e.g., save money by using a cheaper resource, increase productivity of crops as TSE has more nutrients, conserve fresh water by relying on TSE, maximize profit by decreasing the expenditures and increasing the profit). However, are farmers aware of the environmental and health associated impacts? Are farmers familiar with how to implement the needed monitoring programs? Are farmers aware of the positive environmental consequences of using TSE? Will farmers' information requirements vary from those who rejected to use TSE in their farms?

RQ2. What information have farmers received, or would like to receive, to enable them to take an informed decision? What other information should be shared?

To define the requirements, the information shared with farmers needs to be identified, as well as sharing frequency, and the preferred methods. This helps in determining the sufficiency of the communicated information, the advantageous frequency, and the effectiveness of the used methods. The use of TSE in agriculture is a complex process as it has pros and cons that farmers must be aware of before taking decisions. For example, would farmers need to know how to calculate the cost-benefit and how and when will be the return on their investment? What are the trades-off between environmental health risks, price, and sustainability and how are these shown? Is it also critical to understand if the information communicated with farmers is easy to understand? How did this information influence farmers' decision-making process? In addition, how to present all these factors in one single, simple graph that captures the requirements and their relationships?

B. Case Description: Use of TSE in irrigated agriculture in Abu Dhabi

In 2012–2013, an innovative program was launched by the Environment Agency of Abu Dhabi, with the objective of introducing TSE in irrigated agriculture to maximize crops production and minimize the use of groundwater in irrigated agriculture. This case study is used to:

- Validate the developed CGM model: the outcomes of the interviews and meetings help in validating the designed goal models to maximize the use of TSE in irrigated agriculture. Discussions focus on how farmers currently receive information, and why this information should be enhanced and effectively communicated, the expected benefits, the constraints they have faced as well as the benefits of using TSE based on their experiences in the program.

C. Data collection

We reached out to the program's teams to provide access to the program details and current beneficiaries (the farmers). The main data collection method for this research is the literature review (observations from the literature help in portraying the full picture of the model), case studies analyses (enrich data collection and knowledge generation), and semi-structured interviews with the stakeholders, mainly the farmers who have accepted using TSE in irrigated agriculture.

Questions of the semi-structured interviews are of open-ended style, to enable stakeholders to share details they feel appropriate and relevant. Questions cover the main reasons to get involved in the program, the expected benefits, constraints, environmental motivations, sustainability concerns, availability of needed information, at any stage of the program development farmers were engaged, and do they share their feedback with government officials, how and how often. A list of the interview questions is provided in the Appendix.

D. Modeling and Data Analyses

The modeling follows five main steps presented in [17]:

Define and model the CGM goals, refinements, and domain assumptions:

Goals, requirements, functional and non-functional requirements are defined based on literature review and best practices and modeled using the CGM-Tool. A functional requirement is the *MaximizeTSEUtilization* in irrigated agriculture. Non-functional requirements include *ImproveLivingStandards, ProtectEnvironment*, and *NetPositiveRevenue*.

According to [17], elements and refinements can be enriched by user-defined Boolean constraints. This can be expressed in three different methods (i) graphically as relation edges, (ii) textually as Boolean formulas, and (iii) as user assertions. The relation edges and user assertions are both used to develop the CGM model.

In CGM-Tool, users can interactively mark/unmark every goal, task, or domain assumption as satisfied (i.e. true), or unsatisfied (i.e. false). Marking requirements as satisfied makes them mandatory. Unmarking requirements means they are "nice-to-have" or "preferable." *MaximizeTSEUtilization* is asserted as satisfied to make it mandatory.

Realization of the Constrained Goal Model:

After defining the CGM backbone, and the constraints, MaximizeTSEUtilization is proposed as the only satisfied (marked) based on users' assertion. Different realizations can be generated by the CGM-Tool. Those different realizations represent alternative ways of refining mandatory requirements in line with the user-defined constraints and assertions.

Setting preferences in the CGM and checking well formedness:

Once the first two steps mentioned above are done, the next step is setting preferences in the CGM and running the CGM-Tool to generate all possible realizations:

- First, the check well-formedness function is used to test and verify the formedness and the validity of the constrained goal model by analyzing Empty Diagram, Invalid Goal Node, Refinement Validity Check, and Undeclared Variable. A CGM model is well-formed if all of these elements and their relations are modeled and interconnected correctly [32]. The test is performed by calling the Check well-formedness function, and then calling the Run Analysis function
- Second, the model is generated by calling the Generate Scenario function. The model checks for consistency first, and then produces the scenarios. Produced scenarios are saved under the Scenarios Folder (under the developed model).
- Third, by using the Launch reasoner function, the model generates all possible realizations after defining optimization priorities. The selection of the most reasonable one is based on the stakeholders' preferences. However, this third step is not performed under this research due to time constraints and data accessibility limitations. To use the Launch reasoner, SMT variables and global constraints need to be identified by the stakeholders. Stakeholders can express preferences on the requirements, constraints, refinements, and tasks [17]. Preferences are expressed in CGM-Tool by attributing penalties and rewards for requirements and tasks, using numerical objectives to optimize, and introducing binary preference relations between elements and refinements.

IV. Results and Discussion

A. Constrained Goal Model

The results of modeling the minimum requirements for maximizing the use of TSE in irrigated agriculture using the CGM-Tool show that it is possible and practical to include the functional requirement *MaximizeTSEUtilization* in irrigated agriculture, as well as non-functional and optional requirements *ProtectEnvironment, ImprovingLivingStandards*, and *NetPositiveRevenue*, as shown in Figure 1.

Figure 1 presents the overall model with no specific realization. It is presented here to show the main requirements and relations between them in order to maximize the use of TSE in irrigated agriculture:

- *Requirements*: round-corner rectangles in Figure 1 are root goals, representing stakeholders' requirements. According to [11], farmers are interested to use TSE in their farms to maximize their profit, by either increasing their production or decreasing the cost. It was identified in [33], [34], [35] that governments' main objective is to minimize the impact on environment by maximizing the use of treated wastewater in irrigated agriculture.

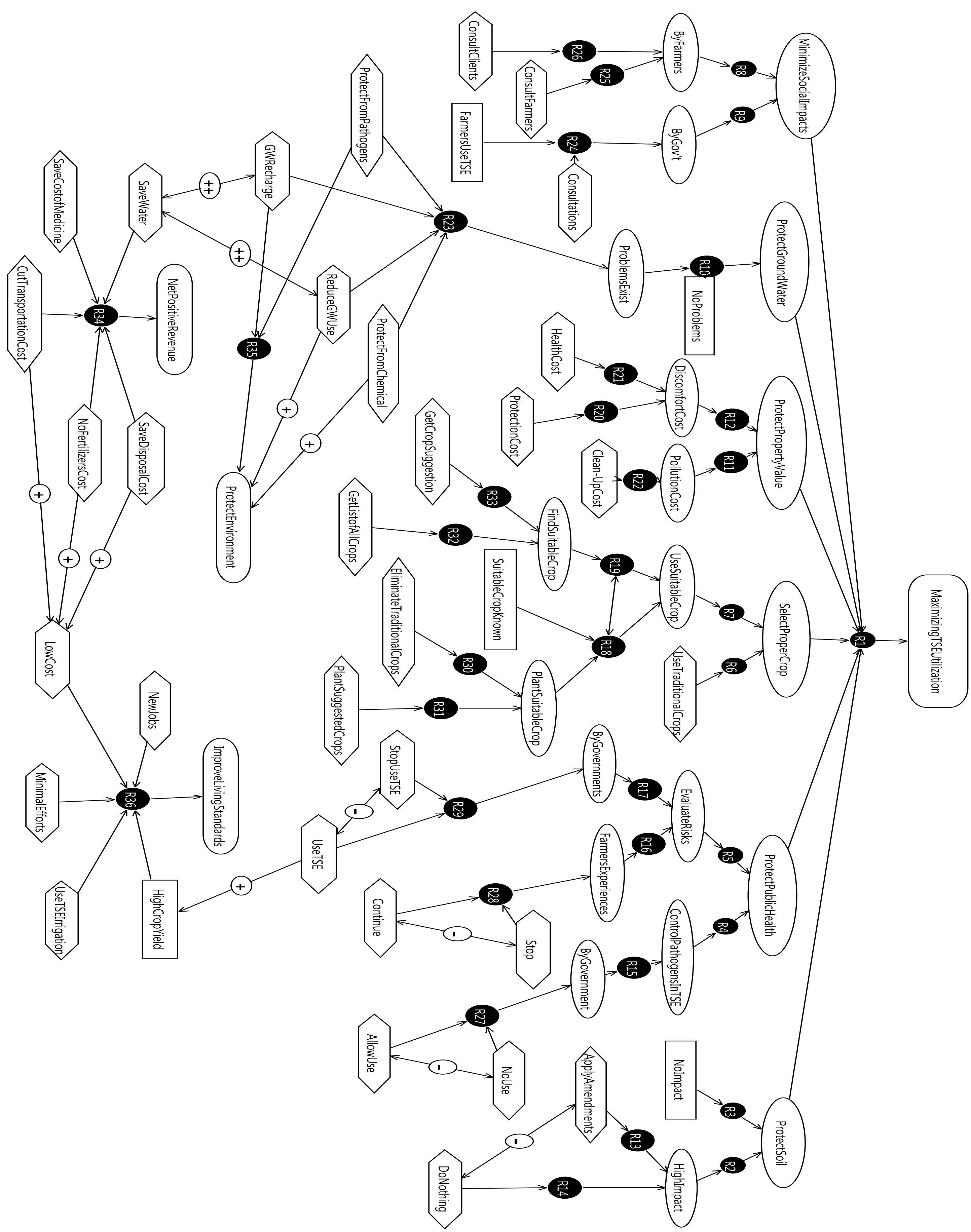

Fig. 1. The constraint goal model of the maximizing TSE use in irrigated agriculture in UAE

The main aim of the constrained goal model, presented in Figure 1 is to achieve the main requirement, *MaximizeTSEUtilization*, which is mandatory. *MaximizTSEuse* has one refinement (R1), consisting of six sub-goals: *ProtectGroundWater, MinimizeSocialImpacts, ProtectPropertyValue, SelectProperCrop, ProtectPublicHealth*, and *ProtectSoil*. Since R1 is the only refinement of the requirement, all these sub-goals should be satisfied in order to satisfy it. However, there might be one more one way to refine an element. For example, *MinimizeSocialImpacts* is further refined either by R12 into the single goal *ByFarmers* or by R11 into the single goal *ByGovernment*. Similarly, *ProtectGroundWater* and *ProtectPropertValue* have one and two possible refinements, respectively.

- The requirements that are not defined as mandatory are optional "nice-to-have" requirements. Those represent desired states of affair needed so the model can be achieved, e.g., *ImproveLivingStandards, ProtectEnviornment*, and *NetPositiveRevenue*.
- *Intermediate goals*: in their research, [22], [14] identified several intermediate goals to be achieved in maximizing use of TSE in irrigated agriculture. Those intermediate goals presented as ovals in Figure 1, including those six intermediate goals *ProtectGroundWater, MinimizeSocialImpacts, ProtectPropertyValue, SelectProperCrop, ProtectPublicHealth*, and *ProtectSoil*. However, since these intermediate goals need other goals to be achieved, 9 other lower-level leaf goals (called here 1-lower-level goals) are developed under the main 6 intermediate goals. Furthermore, 3 of the 9 goals have more lower-level goals. These are named here second low-level goals and defined based on [20], [15], [14]. These goals are *ControlPathogenesInTSE, EvaluateRisks* and *UseSuitableCrops*. The second lower-level goals for these three 1-lower level goals are five goals.
- *Tasks* present as hexagons in Figure 1. 31 tasks were identified under the intermediate goals (the first and second level lower-level goals). Tasks include *ApplyAmendments, ProtectFromChemical, SaveFreshWater, CutTransportationCost, EliminateTraditionalCrops*, and *ConsultFarmers*, among others.
- *Domain Assumptions* are propositions about the domain that need to hold for a goal refinement to work. They are shown as rectangles in Figure 1. Five domain assumptions were identified, *NoImpact, HighCropYield, NoProblems, SuitableCropsKnown*, and *FarmersUseTSE*, according to [14], [34].
- *Refinements* represent the alternatives of sub-elements that are necessary to be achieved. They are numbered black bullets at the merging points of the edges connecting a group of source elements to a target element. For example, (*SuitableCropKnown* and *PlantSuitableCrop*) $\xrightarrow{\text{R19}}$ *UseSuitableCrop*, while R19 denotes the refinement's label. This means that the *SuitableCropKnown* and the PlantSuitableCrop are both necessary alternatives to achieve the *UseSuitableCrop*. Refinements are labeled, so it is easier for stakeholders to review and revise those relationships as necessary.

B. Relation Edges

In the developed model, the elements and refinements were enriched by user-defined constraints, which were expressed graphically as relation edges. In their work [17], they used relation edges in addition to Boolean and SMT formulas. In this paper, the focus is on using relation edges and user assertions.

The relationships between elements and refinements developed in this model are of four types:

- *Contribution edges* (presented as $\xrightarrow{+}$ in Figure 1). Six contribution edges are found in the model. For example, *ReduceGWUse* $\xrightarrow{+}$ *ProtectEnvironment*, means that if the source element ReduceGWUse is satisfied, then also the target element ProtectEnvironment should be satisfied, but not the opposite.
- *Conflict edges* between elements (presented as $\xrightarrow{-}$ in Figure 1). Four conflict edges between elements are found, like *StopUseTSE* $\xrightarrow{-}$ *UseTSE*.
- *Refinement bindings* between two refinements (presented as $\leftrightarrow$ in Figure 1, is used to state that the two refinements are bound. Only one refinement binding is identified, between R18 and R19. The refinements R18, R19 are bound; as such binding reflects that *FindSuitableCrop* $\leftrightarrow$ *PlantSuitableCrop* are also bound. This means that they both represent two different illustrations but of the same global choice [17].
- *Bi-Contribution edges*, presented as $\xleftrightarrow{++}$ in Figure 1). The *SaveWater* $\xleftrightarrow{++}$ *GWRecharge* means that a binding positive refinement exists between the two elements. Two bi-contribution edges are identified in the model, both are related to water saving.

C. Result of Well-Formedness Analysis

The result of running check well-formedness analysis showed that the diagram, goals nodes, refinement, and variables were all identified as the analyses tasks were completed without finding any errors.

D. Scenario Generation

To generate scenarios, one can set *MaximizingTSEUtilization* as the only mandatory requirement, and running the Generate Scenario function, the developed CGM model would have more than 36 different realizations.

The results of presenting the developed CGM model to farmers are summarized below under the two main research questions. The following paragraphs depict main points of discussion and findings, based on farmers feedback:

RQ1. What encourages farmers to use TSE in irrigated agriculture?

The model involves a large number of goals, intermediate goals, tasks, and domain assumptions. The model also shows how complex the relationships between the different elements to maximize TSE use. This makes the work to maximize the use of TSE in irrigated agriculture a complex process with different tasks to be accomplished.

In this model, *MaximizeTSEUtilization* is identified as the only mandatory requirement to be achieved. However, farmers expressed different opinions concerning the nice-to-achieve goals. Although the government might be interested in maximizing the use of TSE, farmers are interested in increasing net positive revenue, or improving their living standards, or protecting the environment, mainly water resources (only one farmer expressed his interest in protecting the environment).

One farmer stated that he frequently asked critical questions as he is *"interested in using TSE for economic reasons"* and that he does not *"use much fertilizers in the farm when using TSE for irrigation as the use of TSE would provide the needed nutrients."* Another farmer, however, had more conservative reasons for using TSE and stated that his previous farming practices were broadly using desalinated water, which is energy consuming and it was his *"belief that using TSE or other water resources is the only way to sustain the limited water resources in the UAE,"* and that using such non-conventional water resource had the personal and social reward of *"more income and less damage and unsustainable use of water resources."* However, two farmers indicated that *"ethical considerations are important to consider when using TSE in irrigation"* as those are an influencing factor in the decision making process and it is essential to *"inform our clients that those crops are irrigated by TSE."* Furthermore, the ethical considerations were also an influencing factor in taking the decision to use TSE as farmers *"believe its our responsibility to conserve water and protect the environment."*

The 32 identified tasks are very important for farmers to be aware of, those are crucial to help farmers in deciding on whether to use TSE in their farms or not. The uncertainty associated with these requirements, as well as the complexity in terms of the number of goals and tasks and their connections made farmers a bit hesitant to use TSE. Furthermore, desalinated water is highly subsidized, and therefore, the use of clean desalinated water is considered an economic viable option, that is also socially acceptable.

RQ2. What information have farmers received, or would like to receive, to enable them to take an informed decision. What other information should be shared?

The main model and all related requirements, goals, tasks, and domain assumptions, as well as, the relations between nodes were present in one single graph. Farmers indicated that they are still not aware of the benefits of using TSE except its reduced cost in respect to desalinated water. Furthermore, farmers indicated that the CGM model is a nice simple way to present the pros and cons of TSE use in irrigated agriculture. Framers indicated also that the soil pollution and groundwater over exploitation aspects have never been discussed; hence, farmers are not aware of the needed procedures to make sure that soil and health are both safe after using TSE.

All interviewed farmers indicated that they had received information about the benefits of using TSE. However, the shared information was *"limited to the cost, quantity of TSE allowed per hectare, and how to get access and be a part of the TSE use program."* Furthermore, the farmers indicated that they had many questions that went unanswered like who is responsible to monitor the quality of the used TSE. Additional unanswered questions included: Is there any guarantee from the government that water is safe and has no negative impacts on crops? Will the use of TSE negatively affect crops' consumption? What kind of crops should be irrigated by TSE? As such, the awareness of the pros and cons of using TSE in irrigated agriculture supported by the needed details should be articulated and considered.

It was also observed during the discussion with the stakeholders that in order to reflect stakeholders' opinion and make the CGM model very practical and flexible, it is necessary to define the impacts of positive and negative constraints. Constraints can be integrated in the model using the Launch reasoner function to optimize intended solutions, as the constraints' impact might be a determinant factor in defining the minimum requirements for framers to use TSE in irrigated agriculture.

V. Validation

Two techniques were used to validate the initial results. The first technique was used to check if the model was built up correctly and if it could be used in this domain, and performed by running *Check Well-formedness Analysis* function of the CGM model. The result of the run confirmed that the model was well formed. This confirmed the *replicability* of the CGM model and the possibility of using it for other technical domains than the computer systems as reported by [17]. The second technique was used to validate if the requirements and refinements captured in the model based on domains experts, are in line with the domain experts' opinion (a group of farmers who have used TSE in irrigated agriculture in Abu Dhabi). Participating farmers (5) agreed that the developed CGM model captures all requirements, however, what was identified as a requirement in the model, was considered as an ultimate goal for farmers. Farmers also confirmed that the presented graph was easy to understand, mainly the way it presented the relationships between the goals and tasks, and the possible refinements. However, farmers recommended that the model should be prepared using the local language, Arabic, as it would have been easier for them to understand.

Farmers expressed their concerns mainly when it came to the social attitude concerning the consumption of crops irrigated by TSE. Therefore, farmers identified social acceptance as the main concern and proposed to consider it as a mandatory goal rather than a sub-goal. Three of the farmers indicated that they would use TSE in irrigated agriculture if local communities would understand the requirements presented in the scenario. Two farmers indicated that environmental and water concerns should be highlighted as the main concerns to convince farmers using TSE in their agriculture. They stated that the subsidized price of desalinated water, makes it easier and safer for farmers to use without thinking of the environmental consequences and the sustainability of groundwater reserves. Two farmers indicated that the main reason for not using TSE before was the limited information they had received. They were also not sure how much they are allowed to use, and what should be done to get TSE to their farms and how. The only issue they were aware of is the cost of TSE as the Government provided it with a subsidized cost.

The main threats to the validity of the results are the standard interview-based study threats and limitations. For example, some farmers were not available to meet with, thus phone conversations were used instead of personal meetings. Furthermore, the research faces a few external threats to validity. These include the coverage (the sample was limited to five farmers due to time constraints), and the low response rates (the questionnaire was shared with a large sample by email, handed to them as a hard copy, and using the phone), however only five responses were received.

VI. Future Work

The future work will include defining different realizations based on Launch Reasoner function. This would entail involving stakeholders to define the values of different tasks in terms of costs (reducing cost), work time needed (minimizing time), and efforts (minimal efforts). Furthermore, penalty could be assigned to tasks and rewards could be assigned to intermediate goals to define quantitative values for tasks and goals to help in differentiating between different aspects of maximizing TSE use in irrigated agriculture. Therefore, further investigation is still needed to understand the mutual influence between requirements and constraints.

Also, the interviewed sample was small due to the time limitations, it is, therefore, necessary to expand the sample by involving a larger number of the interviewed stakeholders. Finally, if the model is tested by a large sample, the full statistical analysis could be done to provide a comprehensive overview of the national minimum requirements to maximize the use of the TSE in irrigated agriculture, and test the CGM model scalability.

VII. Conclusion

We used the goal modeling and reasoning tool in this research to define and model the goals and requirements to maximize treated sewage effluent use in irrigated agriculture. The developed model consists of 61 goals that modeled the importance and urgency of maximizing the use of treated sewage effluent. However, the potential use by farmers in the agriculture sector, which account for high significant share of water use in the UAE, is still limited and faces many challenges, due to a lack of common understanding of the requirements to maximize use. The model elucidated the minimum requirements to maximize the use of TSE in irrigated agriculture, and the required information was found to effectively communicate the goals to the farmers in order to improve ultimate TSE use in irrigated agriculture in the UAE. This work also showed that CGM-tool can be used to present the overall requirements model to the non-technical stakeholders and effectively obtain farmers' feedback on the use of TSE in irrigated agriculture.

Appendix
List of Interview Questions

Introduction questions:

- What is the size of your farm?
- What type of crops you are producing?
- What is(are) the typical planting period(s)?
- What is the average crop production per year?
- How do you normally finance your farm? Do you receive any governments incentives to establish the farm?
- Do you have other sources of income?

TSE use related questions:

- Do you use TSE in your farm? If Yes, since when?
- What is the total amount you use? What is the total amount you can use? Is there any restriction?
- Are you aware of the positive and negative impacts of the use of TSE in irrigated agriculture?
- What are the benefits of using TSE? Have you witnessed any?
- What are the negative impacts of using TSE? Have you observed any?
- How did you know about the TSE use in irrigated agriculture?
- Do you have any kind of monitoring program (monitor the quality of the used TSE)?
- Is the government responsible for monitoring the quality of the TSE used?
- What is the optimal yield in your farm before and after using TSE?
- What is the average yield in your farm?
- Is your production totally irrigated by TSE? Do you use other sources of water in your farms?
- What is the average cost of production in your farm (total cost of using TSE vs. TSE with other water resources, if any)?
- How do you receive TSE? Are you connected by pipes to the source or do you buy using water tanks?
- What are the main risks of using TSE for farmers' income? Did you face any issue?
- What are the main risks you have observed (social acceptance, TSE quality, TSE availability, etc.)?
- What are the health and environmental related risks you have observed?
- If you have observed any risks, how have you managed them?
- Did you receive sufficient information from the Government about the Program?
- How did you receive the info?
- Do you think the shared information was enough?
- What other sort of information you were hoping to get or are still looking for?
- How do you judge if your production was affected by the use of TSE?

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