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Explaining Wastewater Recycling Performance Through Qualitative Comparative Analysis (QCA)

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Summary of key findings

Considerable research has investigated the drivers and barriers towards municipal wastewater recycling, however there has been a dominance of case studies. A challenge for conducting cross-case comparisons is that many factors are known to influence wastewater recycling, and the same factors are not relevant in all contexts. Therefore, a research method is needed that can be applied to an intermediate number of cases – i.e. to balance the benefits of deep, qualitative (small-N) studies with those of broad, quantitative (large-N) studies. In this presentation, we introduce Qualitative Comparative Analysis (QCA) as one such method. In a recent project, we applied QCA to investigate the factors explaining high recycling performance (measured as the percentage of wastewater recycled) among 25 water utilities in New South Wales, Australia. A key finding was that different combinations of conditions explained high recycling performance depending on the type of use – factors relating to water stress and geographical proximity mattered most for agricultural reuse, while high revenue was necessary for heavy (commercial/municipal/industrial) reuse. Furthermore, different causal pathways were associated with each outcome, confirming that the research problem satisfies the underlying assumptions of QCA – i.e. *equifinality* and *conjunctural causation*. Opportunities for future research are outlined, including a critical discussion about the benefits and shortcomings of applying QCA.

Background and relevance

The reclamation, treatment and reuse of municipal wastewater for productive purposes including agricultural, industrial and domestic uses can serve environmental and economic benefits. However there are stark differences in the percentage and volume of wastewater recycled across cities, regions, and countries. Many detailed case studies have described how climatic, policy, regulatory and technological changes have led to a growth in water recycling within specific countries (Radcliffe 2006) or cities (Arbon and Ireland, 2003). However it is an attractive proposition to link specific factors with observed differences in recycling performance across cases, because this enhances the generalizability of findings to new contexts.

When designing a research project involving more than one case, a trade-off must be made between breadth and depth. Large-N approaches have the advantage of breadth (allowing statistical analysis of a small number of variables across many studies), while small-N studies have the advantage of depth (allowing analysis of many variables across a small number of studies) (Larsson, 1993). Given the many and diverse driving forces which are known to influence wastewater recycling performance, it would be advantageous to apply research methods that can bridge these two extremes.

Qualitative Comparative Analysis (QCA) is one such approach that is well suited to research designs of intermediate-N (5-50 cases) (Ragin, 1987). QCA is a set-theoretic method which facilitates the study of causal complexity – i.e. whereby combinations between several factors are hypothesized to influence performance. There are two underlying assumptions of QCA (Berg-Schlosser, 2009): (1) *equifinality* (the same outcome can be explained by different conditions), and (2) *conjunctural causation* (single factors must occur in combination with other factors). Unlike regression which seeks to quantify the average influence of individual variables, QCA identifies the minimal combinations of conditions that are necessary and/or sufficient for an outcome to occur (Vis 2012).

Necessary conditions are always present for the outcome, but do not always cause the outcome. Sufficient conditions always cause the outcome, but the outcome may also be explained by other conditions.

The starting point for a QCA analysis is a selection of case studies, an outcome of interest and a list of factors that are hypothesized to explain differences among the cases. QCA is ideally applied to an intermediate (5-50) number of cases, and the researcher should have sound empirical knowledge about each case to facilitate interpretation of results (Fischer 2011). Each case is represented as a configuration, illustrating the presence/absence of each factor and whether the outcome was present (Rihoux and Ragin 2009). Necessary and sufficient conditions are identified by analysing subset relationships between the conditions (i.e. combinations of factors) and the outcome. For sufficient conditions, the Quine-McCluskey algorithm is applied which uses Boolean logic to identify the unique conditions which always lead to the outcome.

Results

In a recent project, we applied QCA to investigate the factors explaining high recycling performance (measured as the percentage of wastewater recycled) among 25 water utilities in New South Wales, Australia. The 25 utilities had variable performance, with only six utilities recycling more than 30% of their wastewater. Our analysis sought to identify the combinations of factors that were unique to the high performers. We considered how six factors (rainfall; population density; coastal or inland location; proximity to users; cost recovery and revenue for water supply services) influenced recycling performance for two types of use: (1) heavy (commercial/municipal/industrial) and (2) agriculture.

An analysis of necessary conditions found different results depending on the type of use. Receiving high revenue for water supply services was necessary for a high percentage of heavy recycling, while low rainfall and inland location were necessary for a high percentage of agricultural recycling. This finding suggests that policies to promote wastewater reuse would be most effective if they target uses that are feasible for utilities given attributes such as location, climatic factors, and potential revenue from water sales. An analysis of sufficient conditions identified two different causal pathways for each outcome, confirming that wastewater recycling satisfies the underlying assumptions of QCA regarding *equifinality* and *conjunctural causation*.

Discussion

Urban water systems represent complex socio-technical systems whereby both socio-political and technological changes are needed to transition towards sustainable outcomes (Brown et al., 2006). Qualitative (small-N) case studies are important for understanding behaviour in such systems because they allow the researcher to obtain a deep understanding of the specific case and to ensure that the most important drivers of system behaviour are included in analysis. However it is challenging to generalize findings across study contexts. QCA is a research approach that incorporates the benefits of applying detailed case knowledge, but still facilitates cross-case comparison. It may therefore be a valuable approach for future studies in the area of wastewater recycling, and water resources management more broadly.

However, potential users of QCA should be mindful that the approach was initially developed for analysing social science data (Rihoux and Marx, 2013), and has only recently been used to study natural and engineered systems (Basurto, 2013; Srinivasan et al. 2012). New challenges are likely to emerge as the method is applied within new research fields. A particular challenge encountered during this research is that QCA requires the definition of thresholds signifying set-membership scores and selection of a function to scale continuous variables (in the case of fuzzy-set QCA). Ideally, such thresholds should be defined on theoretical grounds, however this proved challenging for some of the variables included in this study, e.g. on what basis can “high” and “low” rainfall environments be distinguished? Although it is known that the approach to variable scaling and threshold selection can influence the results of a QCA analysis, sensitivity analyses have not yet been widely applied within the QCA community (Thiem, 2014). If QCA is to be accepted by natural scientists and engineers, we conclude that this is a research gap that must be addressed.

Nonetheless, from our experience in applying QCA, we found that it offers a unique approach to studying the complex causal pathways explaining wastewater recycling performance. We conclude that the method should be given due consideration in future studies involving an intermediate (5-50) number of cases, when there is detailed knowledge about each case, and when complex causal relationships are hypothesized to explain differences between the cases.

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