



Leading inter- and transdisciplinary research: Lessons from applying theories of change to a strategic research program

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ABSTRACT

Theory of Change (ToC) has been promoted as a useful tool in sustainability research for visioning, planning, communication, monitoring, evaluation and learning. It involves a mapping of steps towards a desired long-term goal supplemented with continuous reflection on how and why change is expected to happen in a particular context. However, there is limited reported experience with the development and application of ToCs in inter- and transdisciplinary research contexts. While some previous publications have focused on ex-post application, there has been little discussion about the process of developing and using ToCs in strategic planning and monitoring in large inter- and transdisciplinary research programs. This article reports challenges and lessons learned from the experience of developing and using ToCs in the inter- and transdisciplinary research program *Wings* (Water and sanitation innovations for non-grid solutions). Challenges include (1) managing time constraints, (2) balancing between concrete and abstract discussions, (3) ensuring diversity in group composition, (4) fluctuating between reservations and appreciation, and (5) fulfilling both service and science roles while leading the ToC process. The experience highlights the importance of alternating formal and informal interaction formats throughout the process, ensuring heterogeneous group formation, involving early career scientists, being responsive to emergent needs and making the added value of developing and using ToCs explicit and tangible for all participants. Although these lessons are mainly derived from developing ToCs within the interdisciplinary program team, they can support other programs in both their inter- and transdisciplinary research endeavors.

1. Introduction

A range of new methods (Bergmann et al., 2012; Defila and Di Giulio, 2018a,b; Hoffmann et al., 2017) and tools (Bammer, 2015; Eigenbrode et al., 2007; Hirsch Hadorn, 2002; Network for Transdisciplinary Research, 2020; Pohl and Wuelser, 2019) has been developed in recent years to support research teams conducting interdisciplinary research (IDR) and transdisciplinary research (TDR). These tools address various aspects of IDR and TDR, including communication, collaboration and integration (O'Rourke, 2017). However, theoretical advances have not always been supported with practical experience and empirical insights. There is a need to test these methods and tools and deliver lessons learned and adaptations back to the research community. Future users need clear guidance on the methods' and tools' key functions, be aware of the challenges they might face in applying such methods and tools, and the strategies they might use to deal with those challenges. There is also a need for practical insights into how

communication, collaboration and integration can be incentivized and strengthened in IDR and TDR.

One tool which has been more recently promoted for inter- and transdisciplinary sustainability research is 'Theory of Change' (ToC) (Belcher et al., 2020; Oberlack et al., 2019; Posner and Cvitanovic, 2019; Schneider et al., 2019; Schneidewind and Rehm, 2019). A ToC maps out a change process in a particular context and is used as a "guiding framework for all stages of thinking, action and sense-making" when a project or a program intervenes in processes of social change (van Es et al., 2015, p. 12). It can be defined as both a process *and* a product (Vogel, 2012b, p. 4). Developing a ToC is an inherently dialogic and reflective process (Vogel, 2012b), which documents the hypotheses and assumptions of researchers and actors (Pohl and Hadorn, 2008) from policy and practice about the key mechanisms and conditions for creating change in a specific context while also describing the causal relationships between project/program interventions and intended outcomes. The ToC as a product is a narrative and visual model (usually

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represented as a flow chart diagram) that illustrates the main activities, actors and results, as well as the assumptions underlying the change process in the short, medium and long term (Belcher et al., 2020; Mayne, 2015).

For several decades, ToC has been an integral part of community and international development projects and has evolved out of two key streams: evaluation theory and social change theory (Vogel, 2012b). In the field of evaluation theory – in particular program theory – growing dissatisfaction with standard evaluation methods that fell short of assessing the *how* and the *why* of complex community projects' successes or failures (Birckmayer and Weiss, 2000; Weiss, 1995) led to the emergence of theory-based evaluation in the 1990s. ToCs have also been influenced by social change theory in the development context. Since the 1970s, when the dominant development paradigm was increasingly challenged due to unsustainable project results, development practitioners and scholars have given more attention to the assumptions underpinning interventions (James, 2011; Stein and Valters, 2012) and started to explore tools in order to “improve development policy and practice” (Valters, 2014, p. 2). As Vogel (2012b, p. 3) notes, “a wide range of development organizations, from grass-roots initiatives in developing countries to donor agencies, have found it an accessible and useful approach” and apply it for planning, evaluation and communication purposes in their projects (Gertler et al., 2016).

A ToC can serve multiple purposes in research, including visioning (Belcher et al., 2017; Oberlack et al., 2019; Weiss, 1995), planning (Belcher et al., 2019; Mayne, 2015), communication, monitoring, and outcome evaluation (Belcher et al., 2020; Douthwaite et al., 2003; van Drooge and Spaepen, 2017), as well as reflection and learning (Halimanjaya et al., 2018; Posner and Cvitanovic, 2019; Ramirez and Belcher, 2018). While these key functions have been frequently discussed in theoretical terms, the practical aspects of developing and using ToC in large IDR and TDR programs have received less attention. Moreover, there is growing literature on the ex-post development of ToCs used for outcome evaluation, but there is little documented experience on how ToCs are used ex-ante as a strategic planning and monitoring tool (Kristof, 2020). This article addresses this gap by presenting lessons learned from developing ToCs within the strategic inter- and transdisciplinary research program *Wings* (Water and sanitation innovations for non-grid solutions) at Eawag, the Swiss Federal Institute of Aquatic Science and Technology.

The article begins by briefly presenting the *Wings* program, followed by a detailed description of how the tool was applied and adapted to the specific purpose and structure of the program. It then discusses the key challenges faced and how they were addressed by the program leaders (first and last author of this article). The article concludes by drawing practical implications for researchers, practitioners, and project or program leaders interested in applying the tool to increase the scientific and societal impact of their research. While these implications are derived from an interdisciplinary context, they also provide insights for transdisciplinary contexts.

2. Case study & methods

2.1. Case study

Wings is a strategic inter- and transdisciplinary research program, which was initiated in 2016 at Eawag. This ten-year program aims to explore and develop novel non-grid, small-grid and hybrid water and sanitation solutions in different socio-economic contexts from multiple disciplinary perspectives. *Wings* builds on past and current research projects from four Eawag departments (Process Engineering; Urban Water Management; Environmental Social Sciences; and Sanitation, Water and Solid Waste for Development) and combines them in a single program. Individual research projects are funded by different agencies and implemented collaboratively with actors from research, policy and practice. Projects are organized in four research pillars, with each pillar examining a typical socio-technical configuration (Markard et al., 2012) in at least one socio-economic context. Cross-cutting projects bridge between pillars and bundle conceptual and methodological needs of the program (see Fig. 1). Table 1 presents a more detailed description of the program composition.

The transdisciplinary dimension of the program aims to co-produce knowledge with actors from policy and practice. This is mainly

accomplished at the individual project level. While the *Wings* program itself has a clear transdisciplinary ambition the program leaders have so far focused efforts to foster interdisciplinary communication, collaboration and integration within the program. This includes eliciting and integrating the diverse types of knowledge generated on the project and pillar level. Additionally, it involves developing a coherent and consistent long-term program strategy, i.e. aligning upcoming research proposals and catalyzing new integrated inter- and transdisciplinary research projects with the aim to support the transformation of the urban water sector towards sustainability (Eawag, 2018).

The decision to develop ToCs for *Wings* at project, pillar and program level was made for several reasons. In line with the key functions described in the literature, the tool was expected to support the research team in creating the ‘bigger picture’ about change processes in the urban water sector in different contexts (visioning), defining the program’s contributions to these processes and identifying specific interventions in the short, medium and long term and related milestones at pillar and program level (planning). Additionally, the tool was intended to support the research team in monitoring change processes in the urban water sector and evaluating the outcomes of interventions defined at pillar and program level (monitoring and outcome evaluation). It was also intended to facilitate continuous reflection and learning about change processes in the course of the program (reflection and learning). Finally, the tool was expected to strengthen interdisciplinary communication and collaboration across all academic positions and departments involved and to foster integration across projects to identify, explore and generate synergies and add value to the projects. While a thorough analysis of the extent to which these expectations and intentions were effectively met is beyond the scope of this article, the authors envision another publication to address these questions adequately.

2.2. Methods

Qualitative methods were used to document, analyze and synthesize the ToC development process (Wittmayer and Hölischer, 2017). These included bilateral interviews, participant observations during meetings, workshops and retreats, joint critical reflections via structured feedback sessions as well as research diaries (Hyers, 2018). Bilateral interviews and joint reflections with program members were used at different points to critically review the ToC process and provide feedback to the program leaders. Participant observations and research diaries were employed by the program leaders to individually document challenges experienced in leading the ToC process, formulate open questions and derive lessons learned for future meetings, workshops and retreats. Ex-post self-reflections following each meeting, workshop or retreat served to encourage the program leaders to jointly reflect on the ToC process and its intermediate results. Formal interviews, meetings, workshops and retreats were recorded with the consent of all participants and transcribed, providing an immensely rich empirical basis for analysis and ex-post self-reflection. The different challenges experienced and respective strategies developed during the ToC process were discussed and analyzed with 10 Eawag external experts in the fields of IDR and TDR, and enriched with contributions from the second and third authors of this article based on their experience with a range of other ToC processes. All program members validated earlier versions of this article.

3. ToC development process

There are many different ways of developing and presenting a ToC. Key components of a ToC are ‘activities’ (i.e. the actual project work, including research, communication and interaction with key actors), ‘outputs’ (i.e., the knowledge, innovations, capacities and/or relationships generated by the project), ‘outcomes’ (i.e., actions of key actors due to changes in knowledge, attitudes, skills, and/or relationships resulting from project or program outputs and interventions), and ‘impacts’ (defined as benefits realized in social, institutional, economic and/or environmental conditions resulting wholly or partially from a chain of events to which the research has contributed) (Belcher et al., 2020, 2018). This chain of activities and outputs leading to outcomes and culminating in impacts are called ‘impact pathways’. ‘Interventions’, in turn, refer to a set of deliberate activities of a project or a program aimed at contributing to social change processes

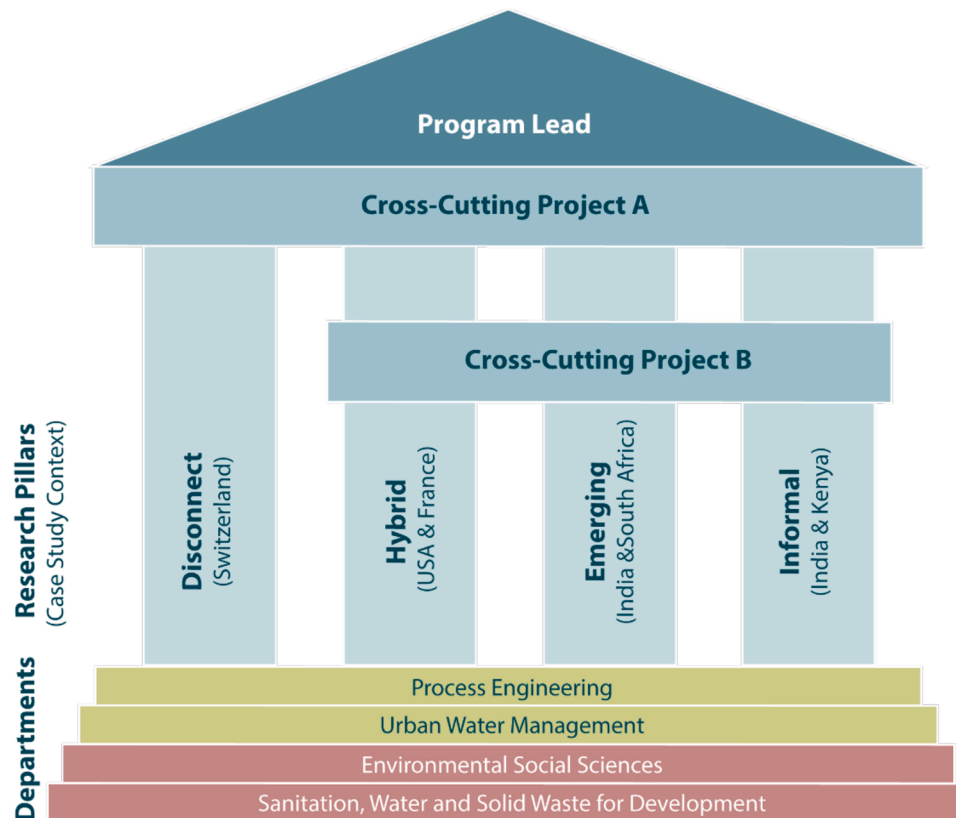


Fig. 1. Wings Program Structure. Engineering Departments (Green) and Social Science Departments² (Red).

(Belcher and Palenberg, 2018).

Two structured retreats, twelve workshops, four program meetings and 24 bilateral meetings were used to develop ToCs at project, pillar and program level with the interdisciplinary program team at Wings. Fig. 2 summarizes the process of developing ToCs at the different levels and illustrates the interaction formats and the amount of time invested at each level (see also sections 3.1, 3.2, and 3.3).

Developing a ToC is a highly dynamic and iterative process that requires multiple feedback loops and periodic revisions. In the following, the ToC development process at each level (project, pillar, program) will be detailed, distinguishing between two approaches: ‘forecasting’ and ‘backcasting’. As many projects were already planned, the ToC process at the project level focused on forecasting; that is, analyzing the likely outcomes and potential impacts of one specific intervention or output. At the pillar and program levels, more emphasis was placed on backcasting, starting from the desired impact and moving ‘backwards’ to identify necessary long-term changes first, followed by changes in the medium- and short-term. This supported reflection about opportunities and constraints of change processes in the urban water sector, as well as identification of potential new research activities and interventions. In practice, ‘forecasting’ and ‘backcasting’ relate to the starting point of each approach; the program leaders iteratively applied and alternated both approaches throughout the process.

3.1. Project level

In a first series of 13 bilateral meetings with junior researchers (Scientific Assistants, PhD Students, Postdoctoral Researchers) and senior researchers (Group Leaders, Department Heads and Directorate Members) from both engineering and social sciences departments (see Fig. 2), ToCs at project level were documented (forecasting) following the method described by Belcher et al. (2020). Each bilateral meeting modeled one element of a ToC (as opposed to trying to develop an all-encompassing project ToC at once). The focus was on mapping how a particular output (e.g. an analysis of policy options communicated through a policy brief) or a specific intervention (e.g. a stakeholder workshop designed to build shared understanding of complex

problems and potential solutions) would inform and influence actors’ behaviour. Provided with guiding questions one week before the meeting, researchers were asked in the meeting to first specify the overall purpose and intended societal impact of the project. They were then requested to develop a ToC starting from the selected output or intervention to define (i) which actors would be reached by the output or intervention (reach), (ii) how it would influence the knowledge, attitudes, skills and/or relationships of these actors (capacity change), (iii) what these actors would do differently as a result of these changes (behavior change), (iv) what direct benefits would arise from these changes (direct benefits), and (v) what implications these benefits would have on society (societal impact) (Mayne, 2015). For each project, the components were first mapped and clustered around an impact pathway (forecasting), and then placed within a nested spheres diagram (‘sphere of control’, ‘sphere of influence’, ‘sphere of interest’) (Belcher et al., 2020). Finally, the underlying theoretical and contextual assumptions as well as risks and opportunities of the ToC were identified. Theoretical assumptions here refer to suppositions about the mechanisms or causal processes that explain why a change is expected, while contextual assumptions relate to the conditions of the system in which the project is operating (Belcher et al., 2020). Risks and opportunities, in turn, refer to uncertainties which, if realized, might hinder or help the achievement of project goals. All mapped ToCs were digitalized by the program leaders and validated by the respective researcher to ensure accuracy. An example is presented in Appendix A.

3.2. Pillar level

Pillar level ToCs were developed iteratively between June 2019 and March 2020, starting with a two-day retreat with Wings senior researchers (see Fig. 2). Researchers were divided into two groups, mixing engineers and social scientists, and asked to follow a step-by-step procedure facilitated by the program leaders and supported by guiding questions developed based on Vogel (2012b):

Step 1: Each group developed an impact statement for one research pillar. The impact statement expressed a common vision and an overarching goal that the research pillar would aim to contribute to but would not be

Table 1

Composition, purposes and focus of the program and its pillars (Scientists: SA = Scientific Assistant, PhD = PhD Student, PostDoc = Postdoctoral Researcher, GL = Group Leader, DH = Department Head, DM = Directorate Member; Departments: ENG = Process Engineering, ESS = Environmental Social Sciences, Sandec = Sanitation, Water and Solid Waste for Development, SWW = Urban Water Management).

Level	Pillars					Program
	Disconnect	Hybrid	Emerging	Informal	Cross-Cutting	
Purpose	Understand and address challenges and opportunities of alternative systems in high-income countries with highly centralized and ageing wastewater infrastructure	Technical development and optimization of urine separation and treatment as well as greywater recycling to regenerate water with high chemical and microbial quality	Support decision makers and niche players in middle-income countries on how to transition towards holistic alternative solutions that allow for meeting growing demands while recovering valuable resources	Understand the broader complexities of heterogeneous sanitation systems and give guidance for transitions to an improved state in informal settlements	Bundle conceptual and methodological needs of the pillars and/or the overall program in order to leverage synergies within the inter- and transdisciplinary research program	Explore and develop alternative urban water systems (=non-grid, small-grid and hybrid) from different disciplines and fields across different contexts and support socio-technical transitions and societal transformations towards sustainability
Research Focus	Where and when is it appropriate to disconnect from the central system and to implement alternative systems? Which potential infrastructure transition paths can be identified?	What are viable alternatives for full-scale applications that collect and treat the wastewater flows separately according to the type and concentration of their contaminants?	What is the potential of lead-markets for alternative systems in emerging markets characterized by rapid urbanization and an expanding middle-income population?	What are enabling and hindering environments for introducing alternative systems in informal settlements lacking basic services and decent housing?	What are institutional barriers of alternative solutions across different contexts? How can inter- and transdisciplinary integration be strengthened within the program?	How can alternative urban water systems be understood and analyzed from an inter- and transdisciplinary perspective?
Type of Projects	Disciplinary (1) Interdisciplinary (2) Transdisciplinary (2)	Disciplinary (3) Transdisciplinary (3)	Disciplinary (1) Interdisciplinary (1)	Disciplinary (1) Interdisciplinary (2) Transdisciplinary (1)	Disciplinary (2) Interdisciplinary (1)	Disciplinary (9) Interdisciplinary (5) Transdisciplinary (6)
Case Studies	Switzerland	France, USA	India, South Africa	Kenya, India	USA, India	All
Disciplines and Fields	Decision Analysis, Environmental Engineering, Human Geography, Transition Studies, Urban Water Management	Environmental Engineering, Innovation Studies, Process Engineering, Transition Studies, Urban Water Management	Environmental Engineering, Decision Analysis, Human Geography, Innovation Studies, Transition Studies, Urban Planning	Environmental Engineering, Innovation Studies, Human Geography, Multi-Stakeholder Planning, Transition Studies, Urban Planning, Water Policy	Environmental Psychology, Innovation Studies, Inter- and Transdisciplinary Research, Human Geography, Transition Studies	Decision Analysis, Environmental Psychology, Environmental and Process Engineering, Human Geography, Innovation Studies, Inter- and Transdisciplinary Research, Transition Studies, Urban Water Management, Urban Planning, Water Policy
Departments	ESS, SWW	ENG, SWW	ESS, ENG, Sandec	ESS, ENG, Sandec	ESS	ESS, ENG, Sandec, SWW
Scientists	SA (1) PhD (4) PostDoc (1) DH (2) GL (1)	SA (2) PhD (3) GL (2) DH (1) DM (1)	PostDoc (1) GL (1) DH (1)	PhD (4) DH (2) DM (1)	PhD (1) PostDoc (2) GL (3)	SA (3) PhD (12) PostDoc (3) GL (6) DH (4) DM (2)
Actors/Partners	Federal, cantonal and communal authorities, engineering consultancies, professional associations, technology companies	Technology companies, architects, cooperatives, engineering consultancies, design offices, philanthropic foundations	Technology companies, utilities, authorities on different levels, policy-makers	Development agencies and banks, philanthropic foundations, NGOs, urban planners	Urban planners, authorities at different levels, utilities, inter- and transdisciplinary research community	Wide range of actors from research, policy and practice across different socio-economic contexts

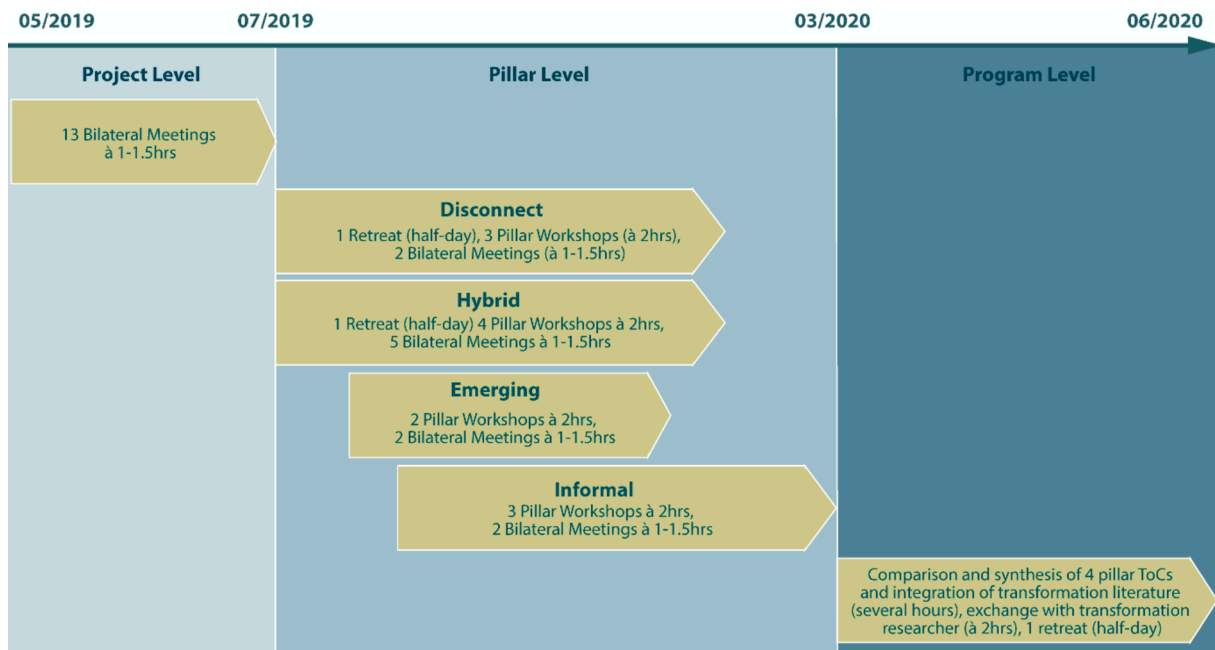


Fig. 2. ToC development process at project, pillar, and program level.

exclusively accountable for (Belcher et al., 2020). Although the strategic program ends in 2025, researchers were encouraged to reflect on an ambitious, but at the same time realistic and concrete goal for 2030.

Step 2: Each group identified eight to ten actors they considered key to achieve the desired impact, classified them as either ‘movers’, ‘floaters’ or ‘blockers’, discussed their interests and rated their influence in realizing this change (Retolaza Eguren, 2011). Links were drawn between actors who already have interacted with each other (e.g. collaborations, exchanges). The colors indicated whether this relationship is primarily conflicting (red) or harmonious (green) (see Fig. 3).

Step 3: Based on steps one and two, each group articulated a sequence of necessary long-, medium-, and short-term changes, working back from the impact statement to identify the conditions that theoretically need to be in place for the intended higher-level changes to occur (backcasting).

Step 4: Each group discussed already planned interventions and defined new interventions to support the changes, reflecting on potential actors to strategically partner and engage with over time.

Step 5: Finally, each group presented their ToC in the plenary. Based on this discussion, a list of relevant gaps and open questions as well as underlying assumptions and uncertainties were compiled for further work.

All ToCs were developed iteratively, seeking validation from program members over the course of multiple meetings and workshops. The program leaders varied interaction formats (meetings, workshops, retreats) and alternated group compositions in terms of scientific hierarchical positions, departments and disciplines (Table 1). Sticky notes were used to document and visualize the discussions. The program leaders recorded most meetings, workshops and retreats, and used the transcripts to extract implicit assumptions that they had missed while moderating the discussion and to feed them back into the iterative loops for further development of the ToCs. Once a pillar ToC was saturated and no new changes or interventions emerged during meetings or workshops, the program leaders organized a last workshop to prioritize interventions. Program members were asked to identify interventions of high, medium, or low priority for achieving the desired impact and to explain their relative choice of priority. They were encouraged to identify and prioritize not only ‘low-hanging fruit’ interventions, but also more challenging ones, especially those with the most promising societal impact. Based on this prioritization, first roles, responsibilities and next steps were clarified, i.e. *who leads what type of intervention together with whom and when*. Each pillar ToC was discussed in one of the monthly *Wings* meetings and thereby further enriched (see again Fig. 2). Fig. 4 illustrates a generic model of the ToC developed at pillar level and its key components. For a more detailed

example of a pillar ToC in terms of content, see Appendix B.

3.3. Program level

The ToC at program level was developed by the program leaders in May and June 2020, building on the program impact statement developed by all senior researchers in the *Wings* Retreat in June 2019. At the retreat, all researchers, including the program leaders, were asked to bring a visual representation (e.g. a photograph or any other object) of the overarching goal of *Wings*. Supported by these visuals, the group formulated an impact statement.

Once all pillar ToCs reached saturation, the program leaders analyzed and compared the four ToCs, identified similarities and differences across the pillars with regard to the long-, medium- and short-term changes and high-, medium- and low-prioritized interventions, aggregated changes and interventions at program level and clustered them around impact pathways that emerged during this process. The program ToC was then compared by the program leaders with insights from a current literature review on societal transformations (Kristof, 2020) and subsequently enriched with key changes and interventions highlighted in the literature. The ‘theory-grounded’ and ‘expertise-based’ program ToC was discussed in a second retreat in June 2020 with the *Wings* junior and senior researchers, and subsequently revised.

4. Challenges and lessons learned

While leading ToC development processes at the project, pillar and program level, the program leaders responded to emergent needs from program members and adapted the approach accordingly, without losing sight of its key functions (Verwoerd et al., 2020, p. 32). In the following, the various challenges faced by the program leaders and lessons learned throughout these processes are discussed and reflected upon.

4.1. Investing and managing time efficiently, while dealing with heterogenous perspectives

The formulation of impact statements at pillar and program level was informed by previous work, in particular the definition of shared goals, developed through numerous workshops and meetings since beginning the program in 2016. With this foundation, the impact statements were developed quickly (30–45 min). Discussions about long-, medium- and short-term changes as well as the identification and prioritization of interventions required several iterations over a longer period of time (see

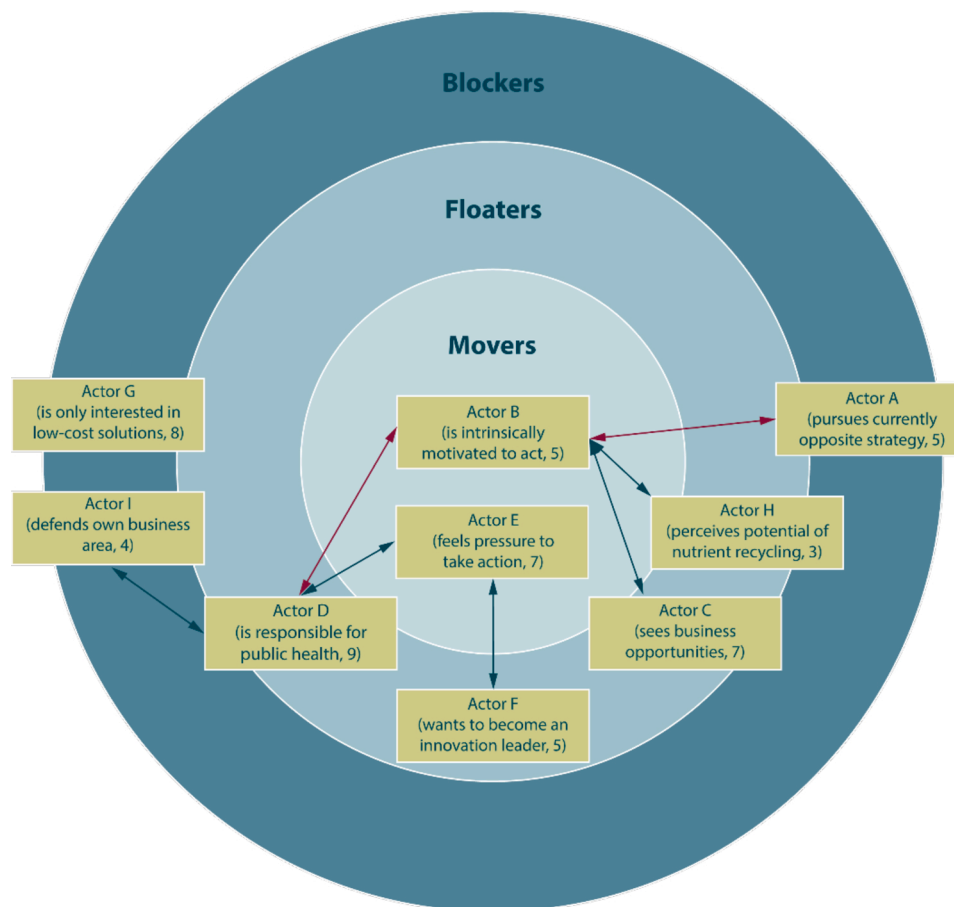


Fig. 3. Actor analysis involving movers (in favor of the intended impact), floaters (undecided/no clear position) and blockers (clear position against the envisioned impact), their interest and influence in realizing the change on a scale from one (low influence) to ten (high influence), and whether relationships have been established, either being conflicting (red) or harmonious (green). Own illustration based on Retolaza Eguen (2011).

Fig. 2. Program members tended to agree on the ‘what’ questions (i.e. the desired impacts) quite quickly, but perspectives diverged on ‘how’ the desired impacts can be achieved and ‘how’ the prioritized interventions can be operationalized. They had different views on how fast change processes develop in the urban water sector, which pathways to focus on, and which actors to engage with to induce and support these change processes. This heterogeneity reflected not only different disciplinary perspectives, but also different worldviews (O’Rourke et al., 2019) and prior experiences of program members, which tend to be understated or neglected in the literature (Ives et al., 2020). The program leaders created space to explore different scenarios (pace of change in the urban water sector and role of different actors) and their consequences for the program’s research activities in more detail. In some cases, it became apparent that previously assumed ‘diverging perspectives’ were in fact complementary, rather than contradictory (e.g. different actors were more or less important at different points of time). In other cases, however, differences remained (e.g. pace of change), but awareness was raised among the program members about the potential implications of different scenarios on their research and the overall program. As stated by one program member:

“I think the key issue here is: what do we take out of this discussion? If [program member] X is right, what difference does this make? If we are unprepared for this development [acceleration of change], we make a mistake. At the same time, it is only a hypothesis. If we now invest all our resources in preparing for this [change], and then it doesn’t happen, this would also be undesirable. These two things, we need to balance.”

Overall, the program leaders did not necessarily aim for a consensus among program members, but a common ground that would still “recognize and value difference” in perspectives instead of assimilating them (Klenk

and Meehan, 2015, p. 166).

Arriving at integrated answers to the ‘how’ questions, required program members to commit substantial time to this inherently iterative process (Oberlack et al., 2019), in addition to their already high workloads. As Maasen and Lieven (2006, pp. 402–403) emphasize, while “there is always time pressure” in research, “the problem is aggravated” in inter- and trans-disciplinary endeavours as “heterogenous inputs” need to be integrated. The initial strategy to iteratively develop the ToC by asking for individual written inputs from program members after meetings, workshops or retreats did not prove beneficial, since senior program members in particular usually have little time to comment on ToCs beyond formal interaction formats. In practice, the ToC process benefitted most from face-to-face interactions during meetings, workshops, and retreats. The time constraints of senior program members required program leaders to produce tangible outputs during such meetings, workshops, and retreats to keep program members engaged. This in turn required thorough preparation i.e. getting familiar with the tool, developing step-by-step guidance, recapping arguments from previous interactions to steer follow-up discussions and set clear and realistic goals for each encounter. To cope with the often limited time available by program members, the program leaders alternated different interaction formats to develop the ToCs further (i.e. formal small and large group workshops, bilateral meetings as well as informal coffee and lunch exchanges) and co-defined the specific purpose of each interaction with program members. Although not all tasks were done in formal meetings, it proved to be essential to focus on the most important and intellectually challenging tasks when meeting face to face (Hampton et al. 2011). These strategies helped to “balance between a too detailed, time-consuming mapping process and a superficial, ‘quick & dirty’ approach that reproduces stereotype thinking and adds no value” (van Es et al., 2015, p. 55).

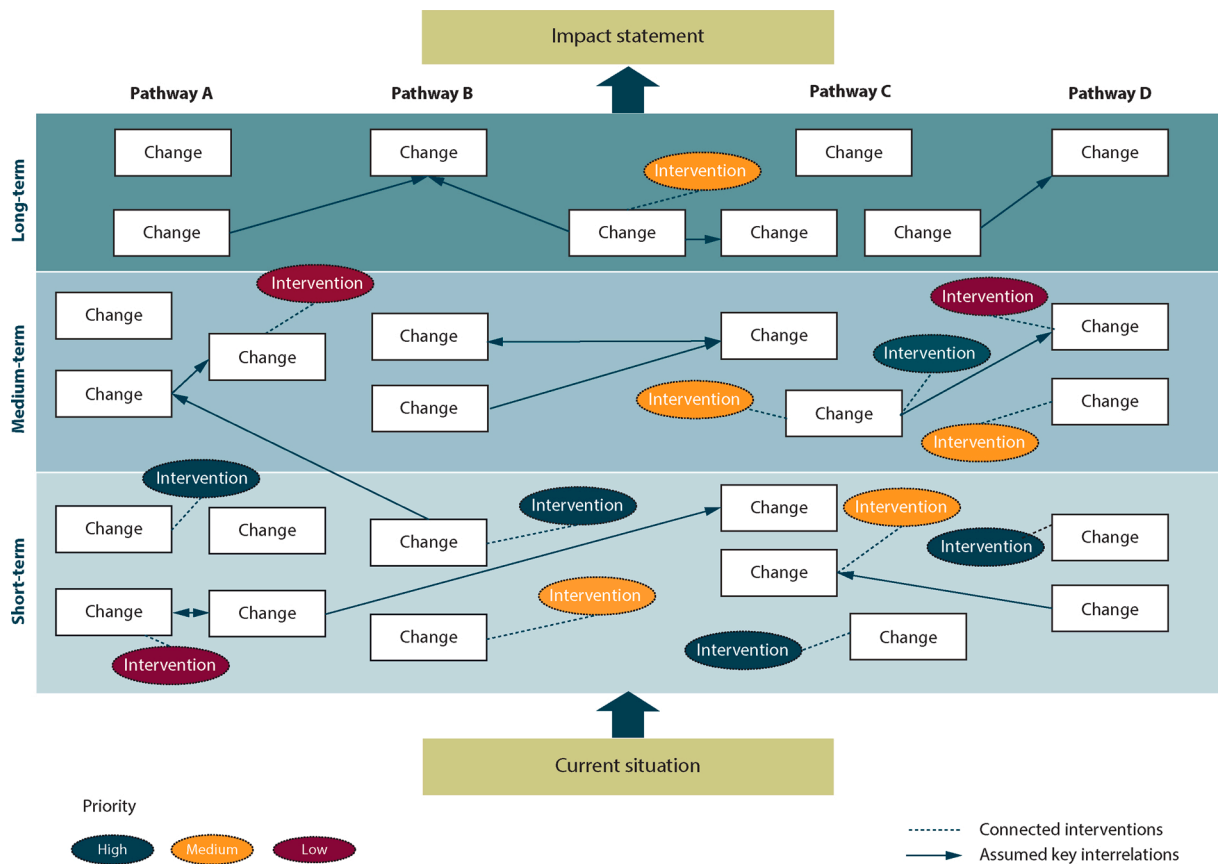


Fig. 4. Generic ToC at pillar and program level developed within Wings (own development).

4.2. Balancing between the concrete and the abstract

Program members initially discussed ToCs on a rather abstract level, which made it difficult to elicit implicit assumptions and brainstorm concrete research activities and interventions. Moving from abstract concepts to specific ‘people-oriented’ statements is a major challenge also found by van Es et al. (2015, p. 41). To ground the discussion empirically, program members were encouraged to identify key actors involved in the change process and specify the behavioural changes required by these actors to enable higher level changes (i.e. *who does what differently at which points of time and why?*). In addition, they were asked to be realistic and deliberate about the underlying mechanisms of change that can be leveraged (e.g. *what is needed beyond knowledge for actor X to contribute to change in organization Y?*), while avoiding ‘leaps of faith’ (Vogel, 2012a, p. 14) and refraining from wishful thinking (e.g. lead markets for new technologies will emerge as a result of research articles).

Achieving a good balance between the concrete and the abstract, is seen as a key feature of a rigorous ToC (Vogel, 2012b) and proved more difficult to attain in some pillars than in others. While the pillar ‘Disconnect’ focuses on only one socio-economic context (e.g. Switzerland), but builds on a large number of past and current research projects, which have generated large amounts of in-depth contextual knowledge, the pillar ‘Informal’ encompasses case studies in several countries (e.g. Kenya and India), involving fewer research projects, and at the same time more diverse and complex actor constellations. To address this challenge, developing and documenting ToCs at pillar level required each pillar team to determine an appropriate degree of specificity and to involve especially Scientific Assistants, PhD Students, and Postdoctoral Researchers with good contextual knowledge.

4.3. Ensuring appropriate diversity in group composition while balancing comfort and discomfort

“Getting the right mix of diverse group members” (Harvey et al., 2018, p. 195) to develop the ToCs in smaller workshops was another challenge.

Bringing implicit assumptions to the surface proved to be more difficult in ‘homogenous’ groups, where group members reaffirmed rather than challenged each other and discussions remained abstract (see 4.2.). In these cases, it was the program leader who critically interrogated unquestioned underlying assumptions, often as a series of questions and answers between the program leader and the rest of the group. ‘Homogenous’ here refers to a lack of diversity in terms of scientific disciplines, research projects, hierarchical positions, experiences and prior collaborations. The program leaders’ assumption that the ToC process would benefit from well-established working groups turned out to be partly flawed. The members of one long-established group, for example, did not break out of their ‘usual way of reasoning’ about transformations in the urban water sector. While well-established working groups tend to entail a lot of trust, which is beneficial for collaborations, they also tend to limit critical discussions about each other’s assumptions. To deal with this, it proved useful to arrange new group compositions by bringing together program members who had not previously collaborated closely, while also ensuring breadth of disciplines, diversity of departments and variety of hierarchical positions involved in these discussions. Junior researchers in particular provided detailed empirical insights and new ideas, which also helped to ground abstract discussions in concrete real-world examples (see section 4.2). Hence, trust and well-established groups are not necessarily key ingredients alone for productive interdisciplinary discussions. While diversity proved essential for eliciting implicit assumptions and steering critical discussions, it brought with it yet another challenge: the need to strike a balance between an “understimulating comfort zone and an overly disruptive discomfort zone” (Freeth and Caniglia, 2020, p. 254). The program leaders were therefore tasked with carefully managing this balance to create a “learning zone”, by treating each perspective with genuine curiosity and avoiding hasty judgments (see. 4.1.).

For facilitating the integration of different perspectives, the program leaders tested two approaches. In some cases, program members were asked at the start of the workshop to individually brainstorm about necessary long-, medium-, and short-term changes and note their ideas on sticky-notes before starting a joint discussion. In other cases, the program leaders initiated group brainstorming and discussion right away, while jointly formulating and

synthesizing the ideas on sticky notes. This latter approach proved to be more effective as terms and ideas could be clarified and discussed in depth before being summarized and stuck to the pinboard. In cases where each program member documented their own ideas separately prior to discussion, the ToC tended to reflect a mosaic of individual perspectives rather than an integrated picture, and therefore required more integrative efforts from the program leaders afterwards.

4.4. Fluctuating between reservations and appreciation

At the beginning, the term ‘Theory of Change’ was met with reservation; some program members argued that the term is extremely fuzzy; others contended that a ‘Theory of Change’ is not a proper ‘theory’.¹ The program leaders responded to this concern by stressing that assumptions are rooted to a certain extent in scientific evidence, but are also informed – to an even larger extent – by mental models (Johnson-Laird, 1983; van Es et al., 2015), worldviews and prior experiences of each program member. They further explained that, although it is uncertain to what extent these assumptions hold in reality, it is crucial to make assumptions explicit since they influence researcher’s and a program’s strategic decisions. By making them explicit, assumptions become hypotheses which can be tested, challenged and refined by different perspectives from policy and practice (Schneider et al., 2019). Such explicit discourse enables learning on how change unfolds in the particular contexts of each research pillar (Belcher et al., 2020), and can inform future research activities and collaborations among different actors. While some program members found these explanations useful for understanding the origin of the term ToC, some reservations concerning the term remained. It could be discussed to what extent renaming the tool might prevent similar misunderstandings in other projects or programs. In addition, the initial reservations highlight the need for clarifying terms and outlining the purpose and utility of ToCs clearly both prior to, but also throughout the development of a ToC.

Another concern was that the ToC was not sufficiently grounded in the literature on societal transformation, as also argued by Archibald et al. (2016). To deal with this concern, the program leaders compared the ToC on the program level with insights from a literature review on societal transformations (Kristof, 2020), exchanged with the author of this review on the ToC at program level, and revised the ToC based on her feedback. They then discussed the ‘theory-grounded’ and ‘expertise-based’ ToC with program members (see section 3).

The ToC development also showed that engaging with different societal actors requires researchers to adapt their research practices and go beyond their traditional ‘observer roles’. The diversification of roles in different contexts and different points in time, and how to delimit them from other actor groups, was critically discussed several times throughout the process. One program member linked this discussion to researchers’ competencies in inducing and supporting such transformation processes:

“What are our core competencies or core mandates as researchers? So which core competencies can we bring into this whole ToC in order to enable things?... It’s not that we have that know-how to change things as a core skill.”

The reiteration of discussions on roles and competencies revealed different perspectives on researcher’s roles, but also the challenge of ‘role-strains’ in inter- and transdisciplinary programs (Parker and Crona, 2012, pp. 265–266). Researchers are not only confronted with multiple demands stemming from their disciplinary fields, but also need to acquire a new skill-set to engage in inter- and transdisciplinary research modes. The ToC development helped to steer a discussion on which competencies are

¹ The term “Theory of Change” may be misleading to some because it implies a single theory. In fact, a theory of change is a set of hypotheses based on several theories about cause and effect in a particular context.

² The classification as ‘social science departments’ relates to the research focus and methods employed within these two departments, while the backgrounds of department members go beyond ‘classical social sciences’ (see Table 1) and in some cases even include original training in environmental engineering.

lacking and need to be developed within the program, and which competencies could be covered by other actor groups. Related to this, some program members also raised concerns about being held accountable for what is stated in the ToC and expected to contribute to all identified necessary changes on top of their already high workload:

“I find it great. There is everything in there [the ToC] what is needed, but at the same time this is the problem of the whole story. When I look at this and imagine that we have to do all of it, then I feel a bit overwhelmed.”

The program leaders clarified that the intention is not to put all the responsibility on the program members, but to use the emerging ‘bigger picture’ for strategy development. This involves taking conscious decisions about the various roles program members assume in different contexts (facilitator, collaborator, enabler, etc.), the different societal actors they engage with and the future research they pursue, hence overall leveraging synergies to induce and support societal transformation processes in a coherent and strategic manner. In addition, it should help program members to prioritize interventions and allocate resources (e.g. personnel, financial), thus facilitate strategic long-term planning.

However, the expressed concern points to a structural tension inherent to inter- and transdisciplinary research programs (Turner et al., 2015): research practices are strongly determined by the current incentive structure of academia, which values a large number of disciplinary publications in short time. Inter- and transdisciplinary collaborations require long-term time investments and produce a broader range of outputs but fewer academic publications per unit of time or effort (Belcher et al., 2015). Program leaders can use tools and strategies to encourage researchers to reflect upon their roles, the societal relevance of their research and can support them in adapting their research practices accordingly. However, these efforts can only bear fruit if “possible conditions for [these] new practices” are created and “room for maneuver” is provided (Åm, 2019, p. 175). To fully realize the potential of ToC-guided interventions, it is essential to recognize and value policy- and/or practice-oriented outputs such as policy briefs or synthesis reports alongside traditional academic publications when evaluating researchers, teams and programs, particularly with regard to career or funding decisions (Schikowitz, 2020, p. 17). The ‘old’ incentive structures in academia, make it hard to live up to the ambitions of ‘new’ inter- and transdisciplinary research modes (Schmidt and Neuburger, 2017). The program leaders addressed this tension by focusing on some interventions that are synergistic with on-going or planned disciplinary activities and others that put more emphasis on inter- and transdisciplinary efforts with new activities and a broader range of collaborators and actors, aiming to contribute to transformation beyond individual project boundaries (Turnhout et al., 2020). The latter required strategic in-depth discussions to adequately deal with the resources of individual members available.

All concerns notwithstanding, program members expressed their satisfaction with the enriched version of the ToC during a virtual program retreat in June 2020. The benefits of the ToC approach (e.g. understanding one’s role and contribution in different contexts, identifying interdependencies between disciplines as well as between science, policy and practice) became apparent and more tangible over time, which resulted in growing recognition and appreciation of the tool. This was summed up by one program member:

“I would say, what we now have is a mapping of the socio-technical systems. So, how the different parts are interconnected and interdependent. I guess that’s a sort of an added value ... that you see there’s lots of interconnections as to what we want to achieve in Wings. And I guess what is also very important ... is that we adopted some systemic perspective.”

To deal with reservations, however, it was crucial to explicate the added value of the tool by explaining the key functions and intentions behind its application and to remain responsive to emergent needs and constructive criticism from program members.

4.5. Fulfilling service and science roles

During the ToC process, the program leaders assumed both ‘service’ and ‘science’ roles (Bammer et al., 2020; Hendren and Ku, 2019; Salazar et al.,

2019). In the service role, the program leaders were, for instance, confronted with a steadily growing amount of data about the program members' implicit and explicit assumptions. To cope with and capitalize on this data deluge, it was imperative to plan from the start how to collect and systematize data (e.g. implicit and explicit assumptions) and how to use this data to strategically lead the ToC process; otherwise important assumptions can be easily neglected. It was crucial to be consciously selective and purpose-driven to successfully cope with the complexity (van Es et al., 2015, p. 49), as was documenting and visualizing data on a regular basis, creating 'material artefacts' (Pennington et al., 2013) to ease the discussion in meetings and keep program members motivated and engaged.

Integrating the various perspectives from different disciplines and different projects into a comprehensive whole constituted a substantial cognitive challenge, and a critical part of the 'science' role of the program leaders. This integration was promoted to a large extent by the two program leaders beyond meetings by identifying relevant gaps and open questions, and determining critical connections and potential synergies between the ToCs at pillar and program level. This was key for allowing the bigger and more integrated picture about change processes in the urban water sector to emerge. Assuming both roles required not only skills in facilitation (Rees, 2001; Schwarz, 2017), but also expertise in the field of the program's topic (Defila and Di Giulio, 2018a,b) to be able to act at the boundaries of the different disciplines involved in the process and recognizing critical connections between them (Hendren and Ku, 2019). Expertise in both facilitation and integration further involves personal dispositions such as openness, empathy, flexibility, adaptability and persistence (Augsburg, 2014; Fam et al., 2017; Guimarães et al., 2019), 'contributory expertise' in building bridges and 'interactional expertise' (Collins and Evans, 2002) "to work effectively and knowledgeably with a team" (Bammer et al., 2020, p. 2). Hence, the program leaders not only led program members step-by-step through the process and facilitated discussions, they also integrated the various contributions, including their own, into a more coherent and consistent whole.

Integrating heterogenous contributions requires, however, not only a significant amount of cognitive effort (Harvey et al., 2018), but also emotional (see 4.3. balancing comfort and discomfort) and social (see 4.4. fluctuation between reservations and appreciation) efforts (Boix Mansilla et al., 2016). Overall, assuming this integrative 'science role' (and balancing it with the 'service role' of coordination, facilitation, documentation and visualization), implied a significantly higher workload than initially expected, and required flexibility and adaptability by the program leaders throughout the process. However, assuming both roles offered valuable opportunities to both develop and strengthen expertise in facilitation and integration, all of which is transferable to other IDR or TDR endeavors (Hampton and Parker, 2011).

5. Conclusion and outlook

The growing interest in ToC reflects the increasing demand for tools which support inter- and transdisciplinary projects and program leaders, ultimately aiming to strengthen the link between research and societal impact. This article presented how ToCs were developed for visioning, planning, communication, collaboration, integration and reflection across departments, projects and disciplines within the inter- and transdisciplinary program *Wings*. Challenges included managing time constraints, balancing the concrete and the abstract, ensuring diversity in group composition, fluctuating between reservations and appreciation, and fulfilling both service and science roles. The article derived and summarized lessons learned from leading a ToC process within an interdisciplinary setting. These insights are also transferable to transdisciplinary contexts, and can support other program leaders in their ambition to apply ToCs in their own research programs.

However, the ToCs developed within *Wings* also have limitations. There is a risk that program members equate the developed ToCs, which represent researchers' assumptions about change, with reality itself, if they are not further contrasted and complemented with perspectives from policy and practice. Furthermore, since the program leaders took a very proactive role in leading this process from the very beginning, there is some risk that ToC

ownership rests with the program leaders and not with program members. Valters (2014, p. 20) supports this concern by stating that during ToC workshops there "was a commitment to a broader reflective approach" about change, but participants were not necessarily "wedded to the use of ToCs *per se*". There is the risk that the ToC process could lose momentum if not driven forward by the program leaders.

To address these concerns, next steps in the ToC process include the further definition of roles and responsibilities for all ToCs within *Wings*, specifying *who* leads *what type* of intervention together with *whom* and *when*, including the subsequent implementation of prioritized interventions. To meet the concern that the ToCs developed so far mainly capture the researchers' assumptions about change in the urban water sector, workshops will be organized with actors from policy and practice to jointly discuss and refine the ToCs. The ToCs at pillar and program level will be revisited every six to twelve months in order to contrast the researchers' initial assumptions against actual changes in the urban water sector, using qualitative and quantitative indicators (based on Hitziger et al. (2019); Maag et al. (2018) and Posner and Cvitanovic (2019)) and the outcome evaluation approach suggested by Belcher et al. (2020).

This will also allow the program to monitor unexpected and unintended outcomes of the interventions implemented, providing insightful lessons about key mechanisms of change. This way, the ToC remains a living and dynamic product and allows for continuous learning across departments, projects and disciplines. Overall, ToCs provide substantial potential for future research by providing a framework to identify and analyze the common pitfalls of disciplinary assumptions about change in contrast to the realities of social change. In addition, they can demonstrate the potential for outcomes and impacts of inter- and transdisciplinary programs for research funders. The authors acknowledge that the use of ToCs can be combined with other tools, which can support inter- and transdisciplinary planning for societal impact by documenting and reflecting on expected changes from research interventions (Network for Transdisciplinary Research, 2020). Documentation and reflection of such experiences is strongly encouraged to support continuous learning for research effectiveness. Furthermore, future IDR and TDR that applies ToCs could further explore and document experiences to what extent ToCs serve as effective boundary objects (Star and Griesemer, 1989) for crossing boundaries between different disciplines, but also between research, policy and practice. It will be particularly interesting to analyze to what extent the development of ToCs enhances inter- and transdisciplinary communication, collaboration and integration by drawing from the empirical evidence gathered throughout this process.

CRedit authorship contribution statement

Lisa Deutsch: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing, Visualization. **Brian Belcher:** Conceptualization, Writing - review & editing, Validation. **Rachel Claus:** Conceptualization, Writing - review & editing, Validation. **Sabine Hoffmann:** Conceptualization, Project administration, Methodology, Writing - original draft, Writing - review & editing, Visualization, Supervision.

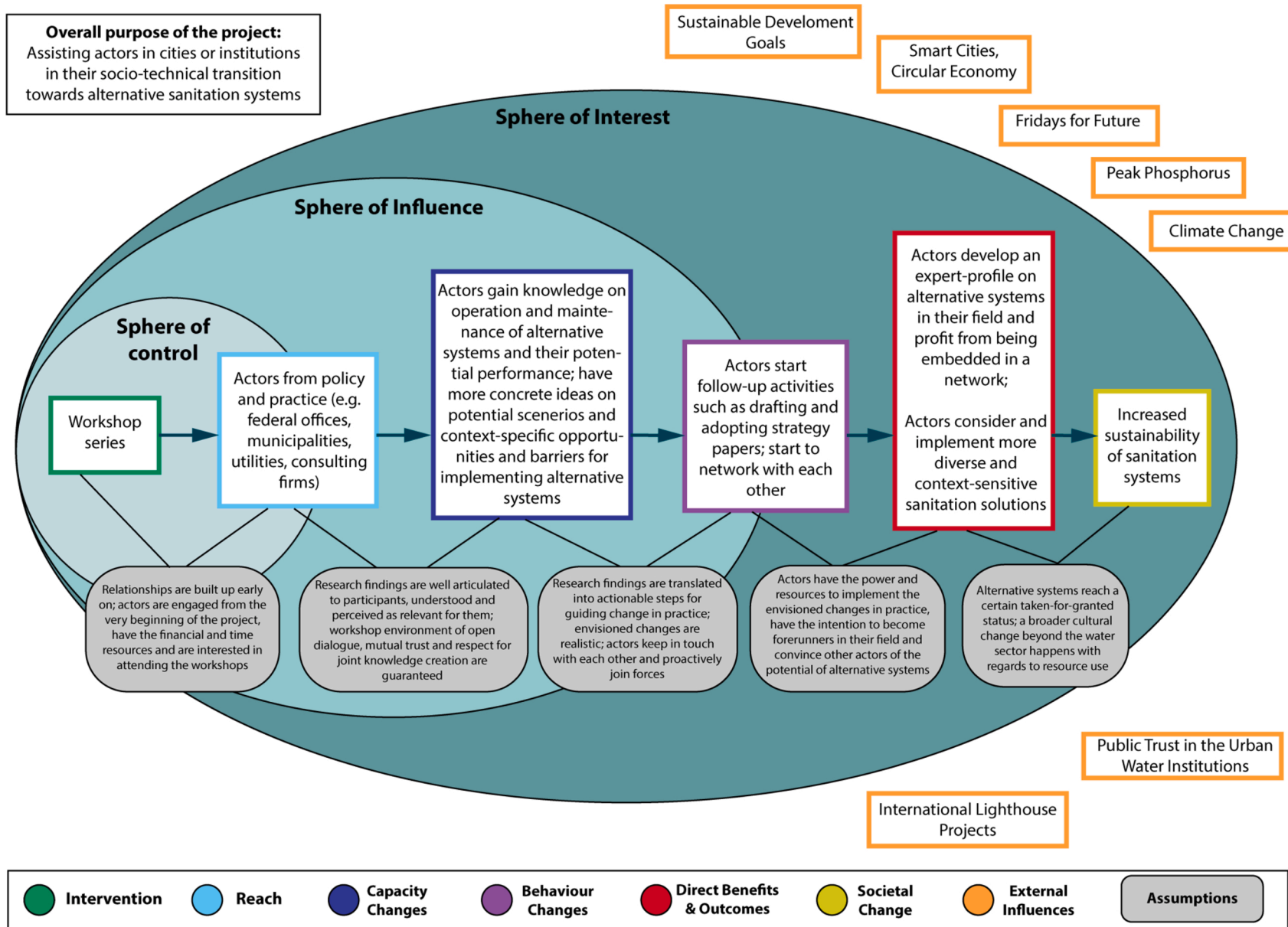
Declaration of Competing Interest

None.

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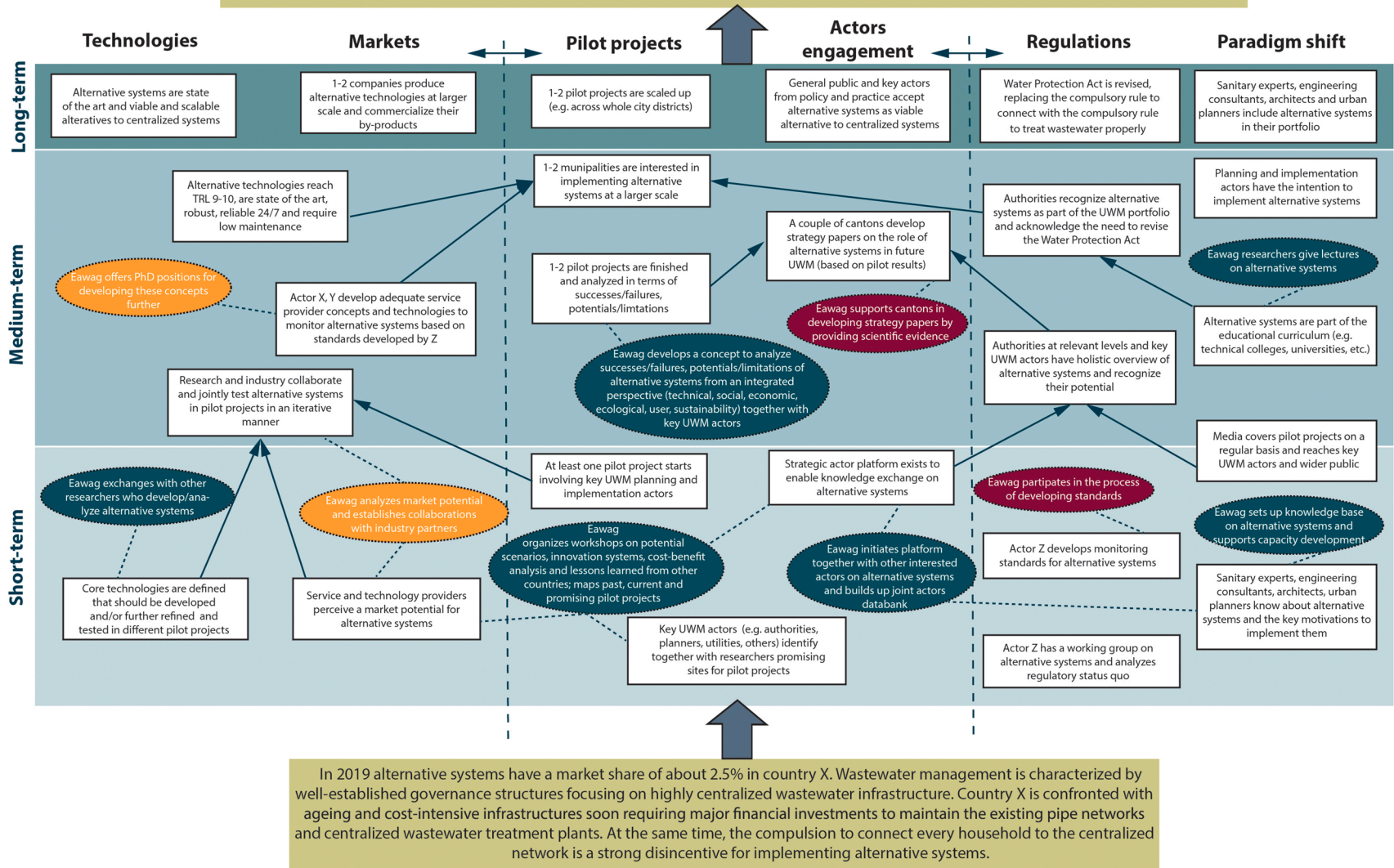
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Appendix A. Example of a developed ToC on project level (forecasting) (adapted based on Sustainability Research Effectiveness (2019) and Mayne (2015))



Appendix B. Example of a developed ToC on pillar level (backcasting) within Wings

By 2030 various viable alternative systems are part of a portfolio for wastewater treatment in country X. Service providers, manufacturers, engineering consultants, authorities and urban planners have competencies for all these systems. Federal authorities have standardized procedures for the approval of alternative systems and it is clear in which contexts they can be implemented. The public appreciates or at least reluctantly accepts these systems. The compulsion to connect to a centralized treatment plant is turned into the compulsion to treat wastewater properly.



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