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Water-smart circular economy – Conceptualisation, transitional policy instruments and stakeholder perception

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A R T I C L E I N F O

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A B S T R A C T

The Circular Economy (CE) is a concept that has gained considerable global attention during the past decade amongst private and public sector actors, politicians and policymakers, citizens and media, and scientific communities. Water and water-related ecosystems, despite their vital role in practically all human activities, have been largely missing from conceptualisations and scientific definitions of the CE. Therefore, this paper presents a definition and concept for a water-smart CE that incorporates water and water-related ecosystems. A water-smart CE would (i) reduce losses of water, energy and valuable substances, (ii) improve water efficiency and productivity, (iii) reuse treated wastewater, and (iv) better protect and lessen pressure upon water-related (both aquatic and groundwater) ecosystems. The paper also touches upon the potential risks of the CE to water-related ecosystems. Policy instruments that could be used to promote a transition towards a water-smart CE in Finland – the setting of the present study – and beyond were also sought. Additionally, actors who provide and/or use water-smart CE solutions were interviewed to shed light on their perceptions about the drivers of, barriers to and potential policy instruments for promoting a transition towards a water-smart CE. Based on the analyses of policy instruments and stakeholder interviews, a mixed use of economic, regulatory and informative instruments is suggested to support the desired transition towards a water-smart CE in Finland and elsewhere.

1. Introduction

During the past decade, the concept of the Circular Economy (CE) has attracted considerable attention in the private and public sectors and amongst policymakers, citizens, media, and academics (see Kirchherr et al., 2017; Reike et al., 2018; Schöggl et al., 2020). The main driver for the establishment of the CE is the present environmentally unsustainable 'take-make-waste' economic system. Climate change, environmental degradation, loss of biodiversity and fresh water scarcity are all increasingly challenging problems (WEF, 2020). The CE is generally regarded as a system-level proposition to correct problems arising from present patterns of consumption and production (e.g. Kirchherr et al., 2017; Korhonen et al., 2018; Schöggl et al., 2020).

Discourses on and the popularisation of the CE are largely driven and promoted by non-academic actors, such as third-sector think-tanks, governmental organisations and companies. Amongst the best-known and most widely distributed presentations on the CE are those published by the Ellen MacArthur Foundation (e.g. EMAF, 2013, 2015). The European Commission has promoted the CE and published several CE-centric policy documents (e.g. EC, 2015, 2020). Although of increasing interest to scholars (see Kirchherr et al., 2017; Reike et al., 2018; Schöggl et al., 2020), the CE has only recently been subject to scientifically argued conceptualisations and analysis (Korhonen et al., 2018; Desing et al., 2020; Schöggl et al., 2020).

As noted by several authors (Kirchherr et al., 2017; Schöggl et al., 2020), the CE has several definitions, most of which were generated by practitioners or policymakers (e.g. EMAF, 2015; EC, 2015) rather than scientists. However, both academic definitions (Korhonen et al., 2018;

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Desing et al., 2020) and well-known practitioner-originating frameworks and illustrations (e.g. EMAF, 2015) ignore water and water-related ecosystems, i.e. aquatic and groundwater ecosystems. This shortcoming must be addressed for several reasons. First, several Sustainable Development Goals (SDGs) set by the UN are either directly or indirectly linked to water and aquatic ecosystems. Second, water-related risks are among the most impactful global threats (WEF, 2020) – indeed, water crises can threaten peace. Third, while current scientific and popular definitions of the CE focus on materials and energy, water is invaluable for practically all human activities. Hence, addressing the benefits and risks of the CE to water and water-related ecosystems would provide a way to make the CE a more plausible and comprehensive concept.

Abstracted water absorbs energy and various substances are dissolved or mixed into it during its use in the different economic activities. Heat and harmful substances can have adverse impacts on water bodies and aquatic life, most notably eutrophication and ecotoxicity. That said, energy, critical raw minerals and other materials can be readily harvested from wastewaters with existing techniques (Kehrein et al., 2020). This would also simultaneously reduce the negative environmental impacts of the treated effluent as substances and heat are recovered rather than released to the environment. It is, however, noteworthy that market barriers may challenge the wider use of such techniques and the recovered secondary materials may not be competitive against ppatheir counterparts made of virgin natural resources (Kehrein et al., 2020).

Another basis for conceptualising a water-smart CE are the risks posed by the CE for water-related ecosystems, which must be properly recognised, assessed and managed. More precisely, reusing wastewater for irrigation purposes, for generating artificial recharge or for industrial processes (Lazarova et al., 2013; Aleisa and Alshavji, 2019) entails microbiological and chemical risks (SCHEER, 2017; Voulvoulis, 2018). Secondary materials may also act as a source of contaminants, thus threatening the quality of natural waters. The realisation of CE principles concerning circular materials provides challenging interfaces between benefits (e.g. conserving natural resources and preserving groundwater aquifers) and risks (impairing water quality) (e.g. Nylén and Salminen, 2019).

The transition from the current economic system to the CE can proceed from the bottom up when companies, the public sector and households change the ways they produce and consume. The design of products, including the use of reusable materials, and the adoption of sharing economy practices are constituents of this transition (e.g. EMAF, 2015). However, Korhonen et al. (2018) pointed out that circularity competes with linearity in markets. Thus, regulatory, economic and information steering are often recommended to accelerate this transition. For instance, the European Commission (2020) promoted several regulatory and economic instruments in the recent CE Action Plan. The promotion of a water-smart CE, however, has received little attention in the popular or scientific literature on the CE. To date, water has been heavily regulated in the EU (Berbel and Espósito, 2017). Existing regulations monitor the condition and use of water resources, different aspects of the water supply, sewerage, and emissions into water bodies. However, the present literature indicates that the economic aspects of the present legislation, such as the Water Framework Directive (WFD), are poorly implemented (Berbel and Espósito, 2017). Additionally, the CE is primarily an economic concept and, as noted by Korhonen et al. (2018), the transition to the CE depends on the economic viability and competitiveness of circular solutions versus linear solutions. Accordingly, although economic instruments will have a key role in transitioning to a water-smart CE, recent research indicates that they are not properly addressed by national CE regulatory policy packages, e.g. in Finland (Fitch-Roy et al., 2021).

The identification of drivers and barriers relevant to the transition to the CE have recently attracted interest from scholars (e.g. de Jesus and Mendonça, 2018; Kirchherr et al., 2018; Masi et al., 2018). That said, scholarship has primarily focused on cultural, market, regulatory and technological drivers and barriers (Kirchherr et al., 2018). Scientific analyses on the factors affecting the transition towards CE that considers specifically water and water-related ecosystems are, however, missing.

To incorporate water into the CE discourse, this article structures the relationship between the CE and water and water-related ecosystems. Based on our analysis, a concept and definition for a water-smart CE is suggested. Economic instruments are also examined to identify which are the most promising candidates for promoting the transition to a water-smart CE in Finland, our case study region, and beyond. Finally, the attitudes of representatives of water-intensive industries and sectors towards the concept, the drivers and barriers involved in the transition to a water-smart CE, and potential instruments for accelerating the transition are examined.

2. Materials and methods

In this section, the conceptualisation and definition of a water-smart CE are first described. Second, the potential applicability of policy instruments to the promotion of a water-smart CE in Finland and elsewhere is discussed and a rationale is provided for the choice of the case study area (Finland). Finally, the perceptions of Finnish stakeholders – users and developers of water-smart circular solutions – concerning the drivers of, barriers to and potential policy instruments for promoting a water-smart CE were examined.

2.1. *Conceptualisation and definition of a water-smart CE*

The conceptualisation of a water-smart CE is aimed at generating a comprehensive picture of water and water-related ecosystems in the context of the CE. The following boundary conditions were set for the conceptualisation: The concept should consider water that has been abstracted from the environment for various economic purposes as well as water-related ecosystems. The concept should also identify the circular solutions that are directly connected to water and water-related ecosystems as well as the risks posed by the CE to these ecosystems.

The conceptualisation of a water-smart CE was developed via the following steps: First, existing literature on the CE and water in its context was examined. Towards this end, a literature search was performed on Web of Science using the keywords 'circular economy' and 'water'. The resulting papers were classified into nine categories: concept papers (1), papers focusing on the CE within a specific sector (2), materials and technologies (3), actors (4), water resources and aquatic ecosystems (5), instruments (6), case studies (7), indicators and quantitative methods (8), and topics other than those in categories 1–8 (9). Also, review papers were identified and further classified into categories 1 through 9. In addition, existing academic literature on the scientific definitions of the CE was critically analysed to assess how it addressed water and water-related ecosystems. Then, the different uses and roles of water and water-related ecosystems in the economy were identified, resulting in the first draft of the concept of a water-smart CE. This initial conceptualisation was discussed in a workshop with 55 relevant stakeholders representing various academic fields (n = 28), private sector businesses (n = 11), ministries (n = 7), NGOs (n = 6) and administrations (n = 2) to provide further insights into the proposed concept. Thereafter, the conceptualisation of a water-smart CE was finalised.

The science-based definition of a water-smart CE proceeded as follows. First, existing science-based definitions of the CE and their justifications (Korhonen et al., 2018; Schöggl et al., 2020) and recent reviews on the CE (Ghisellini et al., 2016; de Jesus et al., 2018; Kirchherr et al., 2017; Reike et al., 2018; Schöggl et al., 2020) were examined to identify how they address water and water-related ecosystems. Second, the frequently referenced non-academic literature on the CE by EMAF (2012, 2015, 2018) was assessed. Third, the results of the literature search were used to identify relevant papers dealing with the definition of a water-smart CE. Finally, approaches that explicitly include water and water-related ecosystems in relation to the CE and that provide a more specific definition of a water-smart CE encompassing elements identified in the conceptualisation were examined.

2.2. Analysis of policy instruments related to a water-smart CE

The second part of this paper deals with the policy instruments that could be used to promote a transition towards a water-smart CE. Towards this end, Finland was used as a case study for the following reasons. First, Finnish decision-makers have set a goal for Finland to be a leading country in the transition to the CE (Sitra, 2017). Consequently, Finland was amongst the first countries to have a national road map towards the CE (Sitra, 2017), which has been subjected to critical academic analysis (Fitch-Roy et al., 2021). Finnish politicians also expect Finland to gain market share internationally in the field of water and clean technologies (Antikainen et al., 2016). The concept of the CE is also being promoted in Finland by organisations like Sitra (a Finnish Innovation Fund), and it has been received well by citizens and private sector actors (Finnish Government, 2021). Furthermore, Finland, as a member of the EU, shares some key legislation with other European countries, such as the water framework directive (WFD). A majority of the water- and wastewater-related instruments applied in Finland (Table 1) are applied widely in other countries as well. Hence, the identification of water- and wastewater-related instruments that could be used to promote a transition towards a water-smart CE in Finland are relevant at least in the context of the EU. To improve the relevance of the case study, comparisons to other EU countries were carried out regarding the use of water- and wastewater-related instruments. Finally, Finland is among relatively few countries to have highly disaggregated national water accounts (Salminen et al., 2018; Weckström et al., 2020) that allow data-based analyses and research targeting water-intensive industries. The concept of a water-smart CE (Section 2.1) is, as such, intended for universal use. In some geographic regions, some elements may be more relevant. An example of this is the reuse of wastewater in water-scarce areas – unlike Finland, a country with extensive freshwater resources. In this study's view, the above factors together make Finland a relevant case study for larger audiences in Europe and beyond.

The analysis scrutinised existing legislation relevant to the pricing and use of water, the quality and costs related to wastewaters and their treatment, and investments in water supply and wastewater treatment in Finland (see Table 1).

Table 1
Finnish legislative instruments and their targets in relation to water supply, use and effluents analysed in the present study.

Target	Act or Governmental Decree
Regulation regarding housing	Limited Liability Housing Companies Act (1599/2009)
Tax treatment of water consumption	Value-added Tax (VAT) Act (1501/1993)
Environmentally motivated tax subsidies	Business Income Tax Act (360/1968)
Regulation of water supply	Water Services Act (119/2001) Act on Support for Water Supply (686/2004)
Other legislation covering water use and wastewater effluents	Environmental Protection Act (527/2014) Water Act (587/2011) Land Use and Building Act (132/1999) Measuring Instruments Act (707/2011) Act on the Organization of River Basin Management and the Marine Strategy (1299/2004) Decree on the Organization of River Basin Management (1040/2006) Decree on the Marine Strategy (980/2011) Consumer Protection Act (38/1978) Competition Act (948/2011) Local Government Act (410/2015)

2.3. Stakeholder interviews

A range of stakeholders (n = 35) were interviewed to analyse their perceptions about the drivers of and barriers to a water-smart CE. Their views on potential policy instruments that could promote its implementation were also investigated. The interviewees were classified into three categories. The first and second categories represented actors who provide (n = 9) or use (n = 15) technical solutions for a water-smart CE. Respondents who both provided and used (n = 11) such solutions were classified into the third category. Another basis for the selection of the interviewees was that they represented various water-intensive industries in Finland. To identify such industries, industry-specific data in national water accounts (Salminen et al., 2018) were used. The selected industries included waste management, mining and base metal production, chemical forestry, aquaculture, food processing, manufacturing of machinery and equipment, manufacturing of chemicals, water supply and sewerage services, and housing services. The number of stakeholder interviews per industry ranged from one to six, with a median of four. To select the interviewees, potential candidates who provided and/or used different types of water-smart circular solutions were first identified according to the following criteria: sufficient coverage across the chosen industries, regional diversity, relevance of the circular solution (according to researchers' subjective respondents typically represented companies operating mainly in Finland, although in some cases their companies were globally oriented.

The interviews were conducted between 2016 and 2019. The first set of interviews (n = 12) targeted primarily those who had brought solutions for a water-smart CE to the market or had implemented such solutions. These interviews dealt with the concept of a water-smart CE and focused on the drivers and barriers encountered in this context. For these interviews, no predetermined questions were used. In the latter set of semi-structured interviews (n = 23), predetermined questions (Appendix I) *were* used. The main themes and questions were defined beforehand but were amenable to elaboration by the interviewees. The questions focused primarily on drivers, incentives, challenges, barriers and policy instruments related to a water-smart CE. In both sets of interviews, specific water-smart CE solutions of which the interviewees were aware or that had already been implemented or examined in their R&D projects were also addressed. As for the interviews, there was neither any institutional review board nor a governing group within the authors' jurisdiction. Instead, the ethical principles of research with human participants in Finland (TENK, 2009; TENK, 2019) were applied.

A memorandum of each interview was compiled based on the interview recordings and notes taken during the interviews. For the first set of interviews, no recordings were made. The memoranda included three subsections that corresponded with the main themes of the predetermined questions: (1) drivers of a water-smart CE, (2) barriers to a water-smart CE and (3) perceptions of potential policy instruments for promoting a water-smart CE. Each interview sought to elicit individual drivers, barriers and policy instruments, which were codified into categories as presented by Kirchherr et al. (2018): cultural, market, regulatory and technological. Thereafter, an exhaustive list of items for each main theme was compiled with the total number of times each item was mentioned. Finally, the ratio of the number of mentions to respondents in each category was calculated to provide a rough estimate of the intra-category differences in the recognition of relevant drivers, barriers and policy instruments.

3. Results and discussion

In this section, existing science-based definitions of the CE concerning water and water-related ecosystems are analysed and alternative ways to address them explicitly in this context are provided. Then, the elements or the concept of a water-smart CE are specified. The subsequent subsection is dedicated to analysing potential policy instruments for promoting a water-smart CE in Finland and beyond.

Finally, the findings from stakeholder interviews are presented to shed light on how the providers and users of water-smart circular solutions perceive the concept of a water-smart CE, particularly in terms of its drivers, barriers and transitional policy instruments.

3.1. Definition of a water-smart CE

Even though the CE has gained considerable attention amongst scholars, leading to a rapid increase in the number of published papers on the topic (e.g. Schöggl et al., 2020), empirical definitions of the CE have emerged only recently (Korhonen et al., 2018; Desing et al., 2020). Such science-based definitions are thus scarce and inadequate for considering water, water-related ecosystems and the recognition, assessment and management of risks posed by the CE. At the same time, water and water-related ecosystems are highly relevant to human life and practically all economic activities.

Consequently, there is a need to introduce water and water-related ecosystems into scientific definitions of the CE. This can be accomplished in two ways: first, by amending current definitions of the CE as proposed by Korhonen et al. (2018)[2] and Desing et al. (2020) to explicitly cover water as well; second, by formulating a bottom-up definition incorporating water and water-related ecosystems, as doing so would allow a more complete and specific description of a water-sustainable – i.e. water-smart – CE. Such an in-depth, bottom-up description would also permit the targeted dissemination of a water-smart CE among practitioners and policymakers alongside academic discourses on the CE.

Towards this end, the following definition was proposed: A water-smart CE is an economic concept through which water is abstracted from the environment to the technosphere within the ecological boundaries of surface and groundwater bodies. In a water-smart CE, abstracted water is used efficiently, thereby avoiding losses. Energy absorbed by and substances mixed or dissolved within water in use are recovered for reuse, thus allowing the recycling of water for various purposes within the technosphere. A water-smart CE implies that secondary materials are used and energy is produced in a manner that rules out significant risks to water-related ecosystems and human health.

While acknowledging the complexities and controversies in the terminology related to water use (e.g. Pfister et al., 2016), the present paper uses the term *water use* instead of *water consumption* as the former is a less ambiguous term than the latter (Weckström et al., 2020). Here, water abstraction is used as a synonym for water withdrawal and water use refers to blue water use.

3.2. Concept and elements of a water-smart CE

The next challenge was to establish a concept that would cover all relevant elements of the economic model defined as a water-smart CE in the previous section. This was accomplished by recognising the various roles of water and water-related ecosystems in human activities and their links to other materials and energy. More importantly, the circular elements of water itself and the substances dissolved into and energy absorbed by it were identified. Finally, these elements were contextualised in the CE to generate a comprehensive and concrete presentation of the concept of a water-smart CE.

To conceptualise a water-smart CE, a literature search was conducted using 'circular economy' and 'water' as search terms. This returned 2107 research papers, of which 81 and 43 fell into the categories 'concepts and frameworks' and 'sectoral studies', respectively (Appendix II). Overall, the papers in the sectoral studies category dealt with, e.g. the water (including wastewater), food and energy sectors. Only a few of the papers on concepts and frameworks corresponded to the conceptualisation presented in the current paper. Nika et al. (2020) introduced a Multi-Sectoral Water Circularity Assessment (MSWCA) framework, which is a model-based approach to symbiotically managing key water-related socio-economic and non-economic sectors. Smol et al. (2020) proposed a CE framework for the European water and wastewater sector. Most of the literature dealt with recovery and reused technologies and specific flows of secondary materials (n = 701) or other topics (n = 868) (Appendix II).

In the non-academic literature, the conceptualisation of water in the CE context was better addressed. The White Paper (Draft 2-b) by the EMAF (2018) points out that the systems diagram for the CE by the EMAF (2015) is not reflective of the water systems. They identified CE principles for both natural and human-managed water systems and specified the different dimensions of water use: water as a service, water as a carrier and water as a source of energy. However, the risks posed by the CE for water resources were not addressed by this paper.

The review of the existing literature underlined the need for a conceptualisation of the CE that systematically addresses water and water-related ecosystems covering both opportunities and risks. This conceptualisation must also facilitate stakeholder interactions on the topic. In this study's concept of a water-smart CE, as illustrated in Fig. 1, first, *water resources are used sustainably*: water abstraction from surface and groundwater sources must occur within the limits of the renewal rate of the water resource. For instance, at the level of an individual aquifer, abstraction must not result in a continuous decrease in the groundwater level. Another example is the abstraction of surface water, which must not threaten the sufficiency of environmental flows (e.g. Richter et al., 2012) and water abstraction for other human activities.

Second, *losses, including leakages of the abstracted water are avoided, as are nutrient losses due to transport by runoff waters from agriculture*. Third, *water abstracted to the technosphere must be used efficiently*; to achieve this, closed circulation and reuse within production sites can be applied. Fourth, *substances dissolved in process waters are utilised at production facilities;* and fifth, *substances harmful to the environment, such as pharmaceuticals or toxic chemicals, are removed from the wastewater at an appropriate stage to minimise their environmental impact*. Towards this end, local, facility-specific treatment technologies can be applied to decrease the load of harmful substances to sewerage and centralised wastewater treatment plants (WWTPs), which are generally not optimised to remove such substances. Accordingly, WWTP operations and the quality of recovered substances can both be improved. Sixth, *energy absorbed and substances dissolved in wastewater are recovered at WWTPs*. Seventh, *wastewater that has been appropriately treated can be reused* in, for instance, manufacturing industries and aquaculture, for sanitation, for the irrigation of crops or green areas, like golf courses, or for the generation of artificial recharge. In all cases, however, high standards must be maintained in terms of risk identification, assessment and management to monitor the microbiological and chemical quality of the reused water, thereby ensuring that the environment and human health are protected and that – at a minimum – legislative requirements are upheld. Finally, *risks to water-related ecosystems are recognised, assessed and managed in all CE applications*.

Services provided by water-related ecosystems are also depicted in Fig. 1. In general, provisioning, regulating and cultural services are particularly relevant for aquatic (or water-related) ecosystems (e.g. Lai et al., 2018). Using these services is related to, e.g. transportation (by water), energy production, food and drinking water production, aquaculture and fishing, as well as to multiple water-related recreational activities (including tourism). Services provided by water in its various forms, i.e. as liquid, snow and ice, are recognised. Water bodies also decompose, immobilise and dilute substances originating from the technosphere.

[2] The following modifications (italicised) to the definition of the CE by Korhonen et al. (2018) were made: The CE is an economy constructed from societal production-consumption systems that maximise the service produced from linear nature-society-nature *throughput flows of materials, water and energy*. This is done by using cyclical *flows of materials, water and energy*, renewable energy sources and cascading-type energy flows.

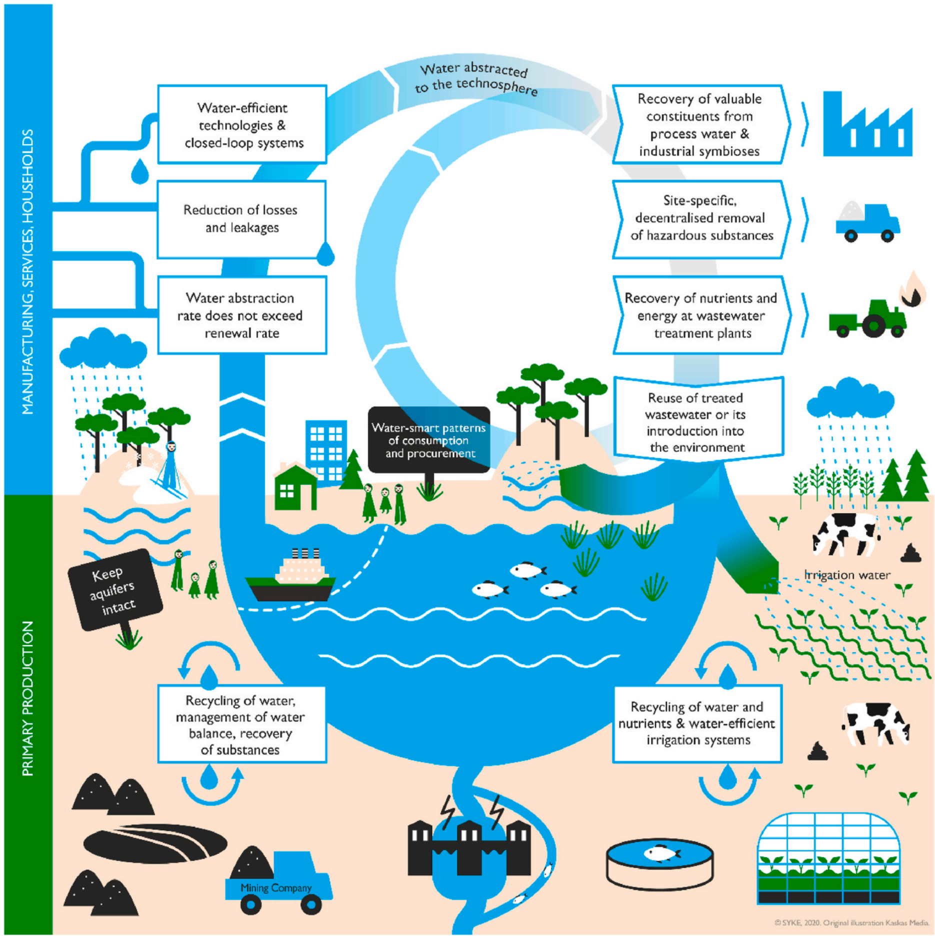

Fig. 1. Water and water-related ecosystems in the CE; elements of a water-smart CE.

Consumer choices and private and public procurement have direct and indirect impacts on water use and water-related ecosystems. Water-smart circular patterns of consumption and procurement can thus also act as a driver and promoter of the transition.

The current paper approaches water, water-related ecosystems and the CE from a systemic perspective. There are naturally similarities between the elements of the water-smart CE and those described in previous literature. Smol et al. (2020) suggested the following '6R' aspects to describe the implementation of CE principles to the water and wastewater sector(s): reduction, reuse, recycling, recovery, reclamation (removal) and rethink. Thematically, the first five aspects refer to the 2nd, 3rd, 5th, 6th and 7th elements of the concept proposed in the current work. The transition to a water-smart CE requires a considerable amount of 'rethinking' as pointed out by Smol et al. (2020). Even though water and wastewater management are services even today, the model on which they operate are by and large linear. Smol and colleagues also argued that rethinking is a transmissive principle rather than being bound to any specific element of the water-smart CE. While they concentrated on human water systems (technosphere), the MSWCA framework by Nika et al. (2020) encompasses natural water systems comparable to the concept introduced in the present paper.

The aspects of water-related ecosystems in the context of the CE and the identification, assessment and management of risks beyond those attributed to water reuse (Voulvolis, 2018) are generally not discussed in water-related CE documents written by practitioners (e.g. EMAF, 2018) or in the relevant academic literature (e.g. Nika et al., 2020; Smol et al., 2020). In the present literature on the CE, the need for risk management in the context of *material cycles* is recognised (e.g. Bilitewski, 2012). However, this theme requires more attention from the perspective of water-related ecosystems since surface and groundwater bodies often act as a recipient of chemical and microbial contaminants that might be present in secondary materials and water. This is particularly relevant for materials that are utilised in, e.g. agriculture and landscaping (e.g. Johansson and Krook, 2021), underground structures in civil engineering (e.g. Nylén and Salminen, 2019), and when secondary water is used for irrigation or for making artificial recharge (e.g. Voulvolis, 2018). In such applications, contaminants may pose a risk to surface water and groundwater quality. The need for risk management together with concerns over the acceptability of circular solutions become apparent when CE-related regulation is shaped in practice. At this stage, struggles between precaution (water quality protection) and resource efficiency (increasing waste recovery) are encountered (e.g. Nylén and Salminen, 2019). The present work argues that it is essential that academically motivated CE concepts address the risks related to contaminants. In this way, such concepts consider both benefits and risks or circular solutions and give a more realistic and plausible outlook of the CE as a solution to environmental sustainability problems.

The assessment of CE strategies, including a water-smart CE, is highly important and merits further study. Briefly, water footprint methodologies (e.g. Hoekstra et al., 2011; Pfister et al., 2016;), water-related environmental accounting (e.g. UN, 2012; Salminen et al., 2018; Weckström et al., 2020), accounting of secondary materials and recovered energy as well as natural capital accounting on water resources (UN et al., 2014) provide tools for this purpose. Traditional indicators, such as water efficiency or water productivity, could potentially be used for assessing the impacts of various policy measures promoting a transition towards a water-smart CE (e.g. UN, 2012; Weckström et al., 2020). Recently, Nika et al. (2020) introduced

Circularity Performance Indicators for the assessment of water-related circularity in multi-sectoral systems as part of their MSWCA framework.

3.3. Policy instruments to promote a transition to a water-smart CE

CE regulatory policy packages and instruments play a central role in promoting the desired transition towards circularity. The following sections assess various water-related instruments as thinkable tools for the promotion of a transition towards a water-smart CE in Finland and beyond. In this analysis, economic instruments are in focus. Indeed, Fitch-Roy et al. (2021) recently criticised the Finnish CE roadmap for its lack of novel economic instruments, thus underlining the need to address such tools if a transition towards the CE is truly desired.

3.3.1. Pricing of water and its elasticity

The pricing of water as a means to promote the sustainable use of water resources is not a novel idea. For instance, 20 years ago, the European commission (EC, 2000) emphasised the use of economic interventions and water charges to achieve sustainability goals. Moreover, principles for functioning water pricing have been previously characterised by, e.g. the European Commission (EC, 2000) and Andersen (1995). In brief, pricing should (i) be related to the usage volume, (ii) cover all related expenses at all water-using sectors, (iii) include both surface and groundwater, (iv) avoid excess administrative costs, (v) allow a sufficient implementation period, and (vi) avoid artificially low water pricing as a tool for socially rationalised compensation.

However, water pricing as a tool of water policy and – in our view – for promoting a water-smart CE encounters is challenged by the low elasticity of water pricing, at least in households. Based on the literature, the elasticity of water pricing is low for multiple reasons (e.g. Termes et al., 2015). First, the contribution of water use to the overall spending of households is low; second, water is a necessary good; and third, water cannot generally be substituted. Indeed, Dalhuisen et al. (2003), Reynaud (2015) and Dige et al. (2017) have found that water pricing had insignificant to no impact on the water use volumes in European households. Meta-analyses by Espey et al. (1997) and Seebri (2014) had similar conclusions: the price elasticity of water was well below 1 in households, indicating low price elasticity. Therefore, other informative instruments are needed for the promotion of a water-smart CE.

As mentioned above, water pricing should be related to the usage volume, implying that water use should be metered in all households, including those within housing corporations. In Finland, since 2011, water meters must be installed in all newly built apartments, yet there is no obligation to use them as the basis of charging. This will likely change soon with the implementation of the EU energy efficiency directive requiring that installed water meters must be used as a basis of charging. Indeed, the Ministry of Environment (2009) has estimated that charging based on metered water use could reduce usage by roughly 10% in households. Ornaghi and Tonin (2015) found that such charging reduced water usage by 16.5% in English households over an 18-month period. Reynaud (2015) highlighted that households reduced their water use over a longer period of time after use-based charging for water was introduced. This may partly compensate for the low price elasticity of water usage in households.

3.3.2. Taxation of tap water, abstracted water, wastewater and emissions

Direct water abstraction and usage by households account for only about 6% of total freshwater use in Finland (Salminen et al., 2018). Therefore, it is essential to evaluate water pricing from a broader perspective than that concerning just households. The VAT for tap water varies substantially, e.g. across the European Union; roughly 60% of the member states apply lowered VAT for tap water (Appendix III). Consequently, water usage is essentially financially subsidised. Notably, several European countries implementing a water abstraction, wastewater or similar selective tax apply a lowered VAT for tap water (Appendix III). Subsequently, the revenues from the water abstraction tax and the water effluent tax have been used to finance a lower VAT for water in many countries.

Unlike in Finland, a water abstraction or water supply tax is applied in several European countries (European Commission, 2016). In most of these countries, budget neutrality has been applied by lowering other taxes when introducing these water-related taxes. Their introduction has been aimed at promoting water efficiency and loss reduction from leakages from water mains (European Commission, 2016). Pedersen and Andersen (2017), however, pointed out that except for Denmark, water abstraction taxes in other European countries have remained low for all key sectors in the economy: agriculture, manufacturing industry and households. Overall, for the promotion of efficient water use as part of a water-smart CE, a low VAT for water would be counterproductive.

In Finland, aquaculture, the paper, pulp and cardboard industry, the petrochemical and chemical industries, the metal industry, energy production, and water supply are together responsible for up to 98% of the total volume (10.2 billion m^3) of abstracted water (Salminen et al., 2018). If cooling water (8.2 billion m^3) is excluded, their share is 91% (Salminen et al., 2018). A water abstraction tax would hence target first and foremost these industries.

Wastewater effluent taxes are applied in several countries within the European Union. While the rationale for the tax as well as its magnitude vary from country to country, the income collected is typically assigned to actions to improve water quality and other investments in water supply and environmental protection (European Commission, 2016). According to Bressers (1988), the introduction of a wastewater tax in 1971 led to an 80% reduction in the load of organic substances over 10 years in the Netherlands. By contrast, in France, the water effluent tax has not had a similar environmental impact (Andersen, 1994). According to Müller-Gulland et al. (2015), the wastewater tax has been effective in decreasing emissions of harmful substances to water bodies in Germany. It has also resulted in the development of treatment technologies for industrial wastewaters. However, the German wastewater tax rate has also been criticised for remaining too low to be effective (Möller-Gulland et al., 2015). Also, the transaction costs have been considerable, ranging from roughly 50% at the time of the introduction of the tax to 13–21% more recently. Pollutant-based wastewater effluent fees and (stricter) limits for emissions were mentioned by our interviewees. Economic instruments targeting pollutants in wastewaters thus merit further attention as a tool to promote a water-smart CE in Finland and elsewhere.

3.3.3. Taxation of secondary materials and secondary water

Secondary materials and recycled (or secondary) water are competing with primary products in the markets. This is a challenge for any circular solution (Korhonen et al., 2018; Milios, 2021) because considerable investments in processing are needed to ensure good quality of the end product. Resource taxes on primary materials and reduced taxes for secondary materials would improve the market competitiveness of the latter (e.g. Milios, 2021). Evidently, environmental benefits should be a prerequisite for the introduction of such exemptions. An existing example of such tax relief is the Finnish Waste Oil Charge Act (originally 894/1986), which is not collected from oil products manufactured from waste oils. The rationale for this is that for such products, the charge has already been paid once. A similar distinction between primary and secondary materials (and hence, products made of them) could be applied to the taxation of fertilisers or water. Incentive environmental taxes (e.g. Määttä, 2006) could target only primary materials, while secondary fertilisers and recycled water would be exempt from this tax.

3.4. Stakeholder views on the drivers of, barriers to and transitional policy instruments for a water-smart CE in Finland

This subsection discusses the stakeholder interviews, which addressed drivers of, barriers to and policy instruments for promoting the transition towards a water-smart CE. In total, 21 individual drivers (4 cultural, 8 regulatory and 9 market-related) of a water-smart CE were mentioned by the respondents (Table 2). On average, an individual item received roughly six mentions. When grouped (see Table 2), the most frequently mentioned drivers were related to financial benefits and support (11 + 11 + 10 + 5 + 4 mentions), business strategies and image (17 + 11 mentions), requirements by environmental regulations, permits and related documents (11 + 9 + 2 + 2 mentions), and environmental awareness (12 + 7 mentions). This shows that actors have adopted the concept of the CE and expect it to be an economically viable way of doing business. Similarly, environmental regulations and customers' environmental awareness together compel the pursuit of environmental sustainability, for which the CE is of interest (see Table 2).

The frequencies of different types of drivers, barriers and suggested policy instruments amongst the three respondent categories (for a summary, see Appendix IV) were also compared. It should be noted, however, that the interview data were semi-quantitative and hence these findings were indicative. Those respondents who developed or both developed and used circular solutions favoured market-related drivers. For the users of the circular solutions, regulatory drivers were most relevant.

Table 2
Cultural, regulatory and market drivers for a water-smart CE as identified by the Finnish interviewees representing actors who develop (category 1), use (2) or both develop and use (3) solutions for a water-smart CE. The total number of mentions and item-specific ratios between the number of mentions and the total number of respondents in each category are shown. The grouping of the individual items is indicated where applicable. Note: Technological drivers were not identified.

	Driver	Total (n)	Item-specific ratio for categories 1-3		
			1	2	3
Cultural	Positive brand image[b]	12	0.22	0.33	0.45
	Increasing awareness of water use's ecological consequences[d]	12	0.56	0.33	0.18
	Responding to environmental challenges[d]	7	0.33	0.13	0.18
	Willingness to extend organization's social responsibility[d]	1	0	0	0.09
Regulatory	Availability of public financing[a]	11	0.44	0.07	0.55
	Environmental legislation and best available technology (BAT) requirements[c]	11	0	0.67	0.09
	Demands set in environmental permit[c]	9	0.22	0.33	0.18
	Likely future changes in BAT reference documents[c]	2	0	0.13	0
	Possible future changes in legislation	2	0	0.07	0.09
	Legislation limiting the amount of manure spread onto fields[c]	2	0.11	0.07	0
	Specifications in public procurement of waste management	1	0	0	0.09
	European Commission's CE package	1	0	0	0.09
Market	Business strategy[b]	17	0.33	0.4	0.73
	Financial benefits of reduced water use[a]	11	0.33	0.47	0.09
	Likely financial benefits in the future[a]	10	0.22	0	0.73
	Financial benefits associated with recovered by-products[a]	5	0	0.20	0.18
	Reducing costs of wastewater discharge to sewage/wastewater treatment[a]	4	0	0.07	0.27
	Limited availability of raw water	3	0.22	0.07	0
	More efficient use and allocation of resources of the company	2	0	0	0.18
	Increased demand for secondary materials	1	0	0	0.09
	Enabling year-round instead of seasonal fish farming	1	0	0	0.09

[a] financial support and benefits.
[b] business strategy and image.
[c] environmental regulations, permits and related documents.
[d] environmental awareness.

de Jesus and Mendonça (2018) reviewed drivers of the CE presented in the academic literature. Their analysis suggested that regulatory drivers were the most important, followed by market drivers. Both of these two driver categories were also prevalent in the opinions of the interviewees in the present study. This conclusion was made based on the total number of drivers compartmentalised under the different driver categories (Table 2).

Finland is rich in terms of water resources. It is thus logical that domestic water scarcity was mentioned as a driver for a water-smart CE only three times in the interviews. Also, as water abstraction is free of charge or tax, it is not surprising that the enterprises developing solutions to help reduce water use or wastewater generation found the domestic market to be challenging. At the same time, the Finnish decision-makers have set a goal for Finland to be a leading country in the transition to the CE (Sitra, 2017). They also expect Finland to gain market share internationally in the field of water and clean technologies (Antikainen et al., 2016). In the view of the current work, if these goals are to be achieved, economic policy instruments, such as a water abstraction tax, should be considered to modify the domestic markets in favour of a water-smart CE. Indeed, Fitch-Roy et al. (2021) deemed the Finnish CE regulatory policy packages less optimal as they do not promote, e.g. novel economic instruments.

As for barriers to a water-smart CE, the responses were clearly more diverse (n = 38), less concentrated (maximum 7 and on average 2.6 mentions per item) and spread across the four types of barriers (Table 3). However, when grouped, the respondents' concerns were thematically related to ambiguities in and the unpredictability of regulation (7 + 7 + 1 + 1 mentions), problems in market performance and economic viability of water-smart circular solutions (3 + 4 + 3 + 3 + 2 mentions), prevailing negative attitudes or communication challenges regarding circular solutions (3 + 3 + 2 + 2 + 2 mentions), immaturity of the circular solutions (6 + 4 + 4 + 1 mentions), and inadequate understanding and lack of knowledge and expertise (6 + 4 + 1 + 1 mentions). The semi-quantitative data also gave some interesting indications: Market barriers were the least prominent category amongst those respondents who provided or provided and used water-smart circular solutions.

The recycling of nutrients as a circular solution has received significant attention and funding in Finland over the past 10 years (Ministry of Agriculture and Forestry, 2011). This has led to technological innovation in the country, but practitioners still envision substantial market-related, regulatory, cultural and technological barriers prior to the recovery and recycling of nutrients in a water-smart CE.

Kirchherr et al. (2018) studied barriers to the CE in EU countries by means of interviews and a survey. Their results indicated that the main barriers were cultural, especially lack of consumer interest and a hesitant company culture, followed by market barriers, such as low virgin material prices and high upfront investment costs. The cultural barriers evoked in our interviews differed from those in Kirchherr et al. (2018). For instance, lack of consumer interest in the CE was not mentioned as a barrier. This may be because in the present work, companies and other stakeholders that were already active in CE implementation or development and were thus confident in its potential in their industries were interviewed. Kirchherr et al. (2018), on the other hand, surveyed opinions of policy-makers and academics in addition to company representatives. Although the major market barriers emphasised by the interviewees are in line with the findings by Kirchherr et al. (2018), our results concerning regulatory barriers to the CE were found to be clearly more important. CE education at a considerable volume was highlighted by Fitch-Roy et al. (2021) as a genuinely novel approach in the Finnish

Table 3
Cultural, regulatory, market and technological barriers for a water-smart CE as identified by the Finnish interviewees representing actors who develop (category 1), use (2) or both develop and use (3) solutions for a water-smart CE. The total number of mentions and item-specific ratios between the number of mentions and the total number of respondents in each category are shown. The grouping of the individual items is indicated where applicable.

	Barrier	Total (n)	Item-specific ratio for categories 1-3		
			1	2	3
Cultural	Inadequate understanding of personal water use and related costs[e]	4	0.11	0.20	0
	Routine use of mineral fertilisers in agriculture[d]	3	0.11	0.07	0.09
	End-users' suspicion of wastewater-based fertilisers[b]	3	0.11	0.07	0.09
	Reluctance for business-to-business collaboration, outsourcing or buying services[b]	3	0.11	0.07	0.09
	Challenges in communication between companies and authorities[b]	2	0.11	0.07	0
	Small size of water utilities limits adaptation of advanced solutions[b]	2	0.11	0	0.09
	Old-fashioned attitudes prevail in water utilities[b]	2	0.11	0	0.09
	Reluctance to implement novel approaches and technologies[b]	2	0.11	0	0.09
	Competing objectives for wastewater treatment hinder application of resource recovery	1	0	0	0.09
	Lack of economic expertise in water utilities[e]	1	0	0	0.09
Regulatory	Poor predictability of future legislation[a]	7	0.11	0.20	0.27
	Current legislation hinders the use of recycled fertiliser products[a]	7	0.11	0.13	0.36
	Country-to-country variation in regulation	4	0.33	0	0.09
	Lack of clear governmental policies related to resource recovery	2	0	0	0.18
	Requirements for process efficiency are partially low in environmental permits	2	0	0.13	0
	Other environmental interests, such as energy efficiency, are prioritised	2	0	0.13	0
	Country-to-country variation in technical requirements	2	0.11	0	0.09
	Complexity of the environmental permitting process of recirculating aquaculture systems	1	0	0	0.09
	Legislation on landfills hampering resource recovery[a]	1	0	0.07	0
	Requirement of high-quality water in production	1	0	0.07	0
	Changing legislation[a]	1	0	0.07	0
	The poor or varying understanding of politicians in the boards of water utilities[e]	1	0.11	0	0
	Complex regulatory demands for introducing new input waste materials	1	0.11	0	0
Market	High price of recovered fertiliser products/poor price competitivity of secondary materials, e.g. fertilisers[d]	4	0.11	0.13	0.09
	Challenges in finding partners for developing business out of by-products	3	0	0.13	0.09
	Low price of water (including leakage water from water mains)[d]	3	0.22	0.07	0
	Costs of water-sparing technologies for households[d]	3	0	0.20	0
	Long pay-back time for water-smart investments[d]	2	0	0.07	0.09
	Challenges in creating circular business chains	2	0	0	0.18
	Challenges in finding financing for water-smart solutions	1	0	0	0.09
	Poor profitability and lack of infrastructure for the reuse of wastewater for irrigation in agriculture	1	0	0.07	0
Technological	Challenges in finding employees with required technical skills[e]	6	0.33	0.07	0.18
	Lack of easy-to-use solutions for the follow-up and invoicing of water use[c]	6	0.11	0.33	0
	Technical challenges when applying technology in a new context[c]	4	0	0.13	0.18
	Imprecise and incorrectly installed water meters[c]	4	0.11	0.20	0
	Difficulties in getting the first references for developed technologies	3	0.22	0	0.09
	Technical challenges with novel recovery solutions[c]	1	0	0	0.09
	Insufficient quality of new input waste materials	1	0.11	0	0

[a] unclear, unpredictable legislation.
[b] poor market performance and economic viability.
[c] negative attitudes and communication problems.
[d] immaturity of the circular solutions.
[e] lack of knowledge.

CE regulatory policy packages. Interestingly, lack of knowledge and expertise was considered as a relevant barrier to water-smart circularity in the present study.

The scientific literature on the relevance of technical barriers to the CE is ambiguous. de Jesus and Mendonça (2018) reported that technical barriers were paramount challenges to the CE in their analysis of the academic literature. They concluded that even if CE solutions are technically feasible, their practical implementation is often limited by market barriers. By contrast, Kirchherr et al. (2018) reported that technical barriers were not among the most pressing problems. This is in line with the interviews, in which technical barriers – beyond technology related to housing-related metering and invoicing of water use – did not stand out. Instead, several technical solutions for a water-smart CE are already available, but market barriers limit their implementation, a conclusion also drawn by de Jesus and Mendonça (2018) for circular solutions in general.

Masi et al. (2018) investigated barriers to the CE by means of a questionnaire sent to company representatives from various countries. These barriers were related to 'resource and energy utilization efficiency' and 'eco-design' and were in this sense closely associated with our "water-smart" standpoint. Their analysis suggested that for both of these operations, the most pressing barriers were 'lack of awareness and sense of urgency' and 'major up-front investment cost'. This study did not identify a lack of awareness or sense of urgency as major barriers based on the interviews. One reason for this is that most of the interviews targeted companies and other stakeholders that were already aware of and active in the CE. Yet, none of the respondents representing less active companies gave any indication of unawareness of the CE. This might be because the CE is a heavily promoted concept in Finland by NGOs, practitioners, policy-makers and politicians (Finnish Goverment, 2021). Several respondents also considered major upfront investment costs to be a pressing barrier to CE implementation.

Finally, the interviewees suggested 27 policy instruments, which – when grouped together – dealt primarily with financial support for circular solutions (6 + 4 + 4 + 3 + 2 + 1 + 1 mentions), use of informative instruments (7 + 3 + 1 mentions), stricter regulation and more advanced use of economic instruments (7 + 5 + 4 + 3 + 3 mentions) (Table 4). Economic instruments, largely absent from Finnish CE regulatory policy packages (Fitch-Roy et al., 2021), are thus considered relevant for the transition towards a (water-smart) CE amongst practitioners. In line with the suggestions for policy instruments in this work, the respondents also mentioned environmentally motivated taxes that target only virgin and not secondary fertilisers to improve the price competitiveness of the latter. To support getting first references for and mainstreaming novel water-smart circular solutions, some of the interviewees also suggested public platforms to test these technologies and demonstrate them for potential customers.

4. Concluding remarks

In the current paper, a concept and scientific definition for a water-smart CE were presented. This contribution also covers risks potentially posed by the CE to the environment – in this case, water-related ecosystems, an element largely missing in the scientific literature on the CE. This enables a better comprehension of how the CE, water and water-related ecosystems are interconnected.

Financial and business-related benefits, including brand image, were amongst the key drivers for a water-smart CE according to actors who provide and/or use water-smart circular solutions in Finland. This indicates that companies have adopted the CE and its principles in Finland where the CE has been intensively promoted by various parties. Similarly, increasing environmental awareness and tightening environmental regulations exert significant pressure on actors and hence constitute a key driver for a water-smart CE. The respondents identified unclear and unpredictable regulation, negative attitudes towards the CE, lack of knowledge and expertise, and the immaturity or poor market performance of water-smart circular solutions as major barriers for a water-smart CE.

Even though water is a highly regulated resource, e.g. in Europe, the current regulations and economic instruments seem to insufficiently support the transition to a water-smart CE in Finland. Overall, the analysis of existing economic instruments and the stakeholder interviews together identified multiple avenues to promote the transition towards a water-smart CE in Finland and elsewhere. Towards this end, a joint and coordinated use of economic, regulatory and informative instruments is suggested. In regard to economic instruments, taxation of water abstraction and tax relief on secondary materials and recycled water and instruments targeting pollutants in wastewater merit further attention.

CRediT authorship contribution statement

Jani Salminen: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Kalle Määttä:** Data curation, Formal analysis, Funding acquisition, Investigation, Writing – review & editing. **Henri Haimi:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Marjo Maidell:** Data curation, Formal analysis, Funding acquisition,

Table 4
Perceptions of cultural, regulatory, market and technological policy instruments for promoting a water-smart CE as identified by the Finnish interviewees representing actors who develop (category 1), use (2) or both develop and use (3) solutions for a water-smart CE. The total number of mentions and item-specific ratios between the number of mentions and the total number of respondents in each category are shown. The grouping of the individual items is indicated where applicable. Note: Technological policy instruments were not identified.

	Policy instrument	Total (n)	Item-specific ratio for categories 1-3		
			1	2	3
Cultural	Information-sharing and guidance on water use and its consequences for different parties[2]	7	0.22	0.33	0
	Need for public acknowledgement of companies executing advanced water-smart solutions	4	0.11	0.2	0
	Information campaigns on secondary fertiliser products needed[2]	3	0.11	0.13	0
	Research should focus on practical solutions instead of theoretical considerations	2	0	0.07	0.09
	Communication and guidance about secondary fertilisers and about means to reduce leakage water volumes are needed[2]	1	0.11	0	0
Regulatory	Regulation on the installation and use of water meters as a basis of invoicing[2]	7	0.33	0.27	0
	Fees based on pollutants in discharged wastewater[2]	5	0.33	0	0.18
	Waste classification regulation should not prevent recycling materials	4	0.22	0.13	0
	Obligation to mix recovered nutrients in fertiliser products[3]	4	0.22	0	0.18
	Limits for discharged pollutant loads set in environmental permits promote water-smart solutions[3]	3	0	0	0.18
	Agricultural support policies should promote use of secondary fertiliser products[3]	3	0.11	0.13	0
	Tax on mineral (that is, primary) fertilisers[2]	3	0.22	0	0.09
	Legislation should focus on the quality of the final fertiliser products instead of their ingredients	2	0	0	0.18
	Recycling by-products produced in aquaculture systems could be obligated in future legislation[3]	1	0	0	0.09
	BAT reference documents are expected to be effective in terms of water efficiency	1	0	0.07	0
	Demands for REACH registration should be made uniform for all fertiliser products	1	0	0	0.09
	Processed digested biomasses should be granted an end-of-waste status	1	0	0	0.09
Market	Need for financial support instruments for investments in novel water technology[1]	6	0.22	0.13	0.18
	Support for networking and finding partners and customers	4	0.11	0.13	0.09
	Need for financial support for research and development projects[1]	4	0.33	0	0.09
	Financial support to decrease the costs of water-sparing technologies for households[1]	4	0	0.27	0
		3	0.22	0.07	0

(continued on next page)

Table 4 (*continued*)

	Policy instrument	Total (n)	Item-specific ratio for categories 1-3		
			1	2	3
	Need for financial support instruments for investments and pilot projects[1]				
	Need to create and develop market for secondary fertilisers	3	0.11	0	0.18
	Need for piloting platforms	3	0.33	0	0
	Financial instruments to promote the use of biogas and digestate are needed[1]	2	0	0.07	0.09
	Financial support for using secondary fertiliser products in agriculture[1]	1	0	0	0.09
	Financial support for energy recovery at wastewater treatment plants[1]	1	0	0	0.09

[1] financial support for circular solutions.
[2] informative instruments.
[3] stricter regulation and more advanced use of economic instruments.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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