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Defining and operationalizing path dependency for the development and monitoring of adaptation pathways

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ABSTRACT

Adaptation pathway approaches (APAs) have become an increasingly popular means of facilitating local and regional anticipatory planning under the influence of climate change. Many studies in this field of research identify path dependencies as a key barrier to adaptation efforts. However, their respective definitions of path dependency are often vague and impede a comprehensive integration of this concept into APAs. We fill this gap by systematically exploring the constituent characteristics and conditions of path dependency based on the original theoretical literature that emerged in the 1980s and early 2000s. We then propose an operationalization based on examples of flood risk management practice, and highlight ways in which APAs may contribute to revealing and anticipating technological and institutional path dependencies. This conceptual work serves as a comprehensive and systematic baseline for analyzing path dependency in empirical studies using APAs within and beyond the flood risk context.

1. Introduction and problem framing

Adaptation pathway approaches (APAs) have become increasingly popular not only for sequenced adaptation planning under deep uncertainty (Haasnoot et al., 2013; Haasnoot et al., 2012; Ranger et al., 2013), but also for fundamentally reconceptualizing adaptation itself as part of pathways of global and societal change (Wise et al., 2014). Werners et al. (2021) outline how the definition of adaptation pathways and respective analytical approaches have evolved since they first emerged around 2010, which was when threshold-oriented APAs were developed (Haasnoot et al., 2012; Haasnoot et al., 2013; Ranger et al., 2013): These first approaches are firmly built into existing institutional settings and address clearly defined goals and thus options for change. However, they were found wanting in two different dimensions: i) its embeddedness in other societal pathways of change and the potential need for action that goes beyond existing institutional confines (Wise et al., 2014); and ii) the need to take into account multiple stakeholder perspectives and preferences (Bosomworth and Gaillard, 2019). Considering these different elements to different extents has led to a broad variety of applications of APAs that vary in terms of focus and methods (Werners et al., 2021). Threshold-oriented approaches aim to meet short- and long-term needs using quantitatively measurable thresholds to determine the sell-by-date of adaptation measures. Multi-actor approaches focus on the process (i.e. collaborative learning and adaptive capacity building), where the pathways correspond to the plans or visions of different stakeholder groups. Transformation-oriented approaches aim to account for complexities and the potential need for transformative change in the long

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run. Threshold-oriented and multi-actor APAs have in common that they operate within the existing institutional framework and in accordance with their corresponding sets of values, and also in that they are fairly concrete (step-wise approaches). Multi-actor and transformation-oriented APAs have in common that they focus on multiple stakeholders, transformation-oriented APAs, however, actually work from the premise that transformational change is needed. Many of these approaches visualize pathways as a set of management options with decision/tipping points or sell-by dates, indicating that at certain times options need to be reconsidered (Haasnoot et al., 2012, Wise et al., 2014), thus creating possible alternative trajectories. Actual applications of APAs, however, do not necessarily show this level of detail (Barnett et al., 2015; Barnett et al., 2014; Bhave et al., 2018; Butler et al., 2016; Werners et al., 2021).

Despite the fact that many APAs explicitly aim to address path dependency, the concept often remains hard to grasp, as in the broad majority of publications "there is limited explanation of what the concept actually means in the context of environmental policy and climate change adaptation" (Parsons et al., 2019, p. 95). In many cases, path dependency typically includes references to past decisions or "history matters" (Colloff et al., 2017; Sadoff et al., 2015; Sorensen, 2015; Wise et al., 2014). However, historians and social scientists acknowledge that the statement "history matters" is an unhelpful and uncritical truism with no explanatory power (van Buuren et al., 2016). In many other instances, authors describe path dependencies as barriers to adaptation (Barnett et al., 2015; Burnham et al., 2016; Matthews et al., 2015; Smith and Brown, 2014), because they create lock-in effects that heavily restrict subsequent decisions, developments, and capabilities (Pauw and Pegels, 2013; Sheller and León, 2016) and also lead to "policy traps" (Nair and Howlett, 2016). Moreover, these studies do not include any greater detail on the concept and how it could be made operational.

There is literature on flood risk management (FRM), albeit not explicitly making use of APAs, in a way that highlights the usefulness of path dependency. Parsons et al. (2019), for example, analyze what they call development or decision-making paths of river management. Wiering et al. (2017) highlight the usefulness of path dependency in terms of understanding the drivers (or forces) of stability and change in FRM over time. They define path dependency in line with Pierson (2000a, b) as "the tendency of persistence and self-reinforcement of paths and, by implication, the difficulty of changing a path once chosen." They interpret path dependency mainly as a set of self-reinforcing mechanisms that they include and combine with concepts of change in their analysis.

Studies understanding adaptation pathways as dynamic adaptive cycles highlight the idea of self-reinforcing mechanisms and also mention path dependency in this context, however they neither provide explicit definitions of path dependency nor do they link back to the path dependency literature (e.g. Bloemen et al., 2018; Tellman et al., 2018). Thus, while the concept of dynamic adaptive cycles may be useful for exploring path dependency, any clear proposition as to the how is missing and we still lack a formal link between APAs and the conceptual work on path dependency.

In this paper we provide a comprehensive argument for why an extended understanding of adaptation pathways is indeed a means of anticipating path dependencies, while at the same time improving our understanding of the limitations of the approach. We thereby link a theoretical concept and an applied decision-making support approach to their mutual benefit. We first discuss how the constituent characteristics and conditions of path dependency can be identified in backward-looking historical research (Section 2), and illustrate how these characteristics and conditions can be operationalized, with examples from FRM in various European countries (Section 3). We then turn to a forward-looking perspective and propose entry points regarding how path dependencies may be anticipated, overcome, or enabled using APAs (Section 4).

2. Defining path dependency

The original literature on path dependency takes a backward-looking perspective (David, 1985; Arthur, 1989; North, 1990; Thelen, 1999; Pierson, 2000a). In other words, path dependency is seen as a process that has the property of staying on a particular path, so that past decisions and contingent events pre-determine what further steps may be taken. Technologies, policies, or governance modes are locked-in. Self-reinforcing mechanisms contribute to their reproduction and diminish the range of likely alternatives. Initially a concept emerging from evolutionary economics and technological innovations, path dependency was also adopted by other social sciences and as such, has been subject to interpretation, expansion, and thus disagreement over its meaning and applicability (Beyer, 2009; Vergne and Durand, 2010). Few of its characteristics and conditions are undisputed. In fact, the concept has been subject to frequent critique for being inconsistently developed and vaguely applied (Vergne and Durand, 2010). Above all, criticism addresses questions like whether initial situations are relevant or not, whether contingency and self-reinforcement are necessary conditions of path dependency, whether lock-in is permanent, whether change is possible, and, if so, whether/how involved actors can (deliberately) affect change (Beyer, 2009).

Despite being variously interpreted, a set of key characteristics and conditions of path dependency stand out from the multi-disciplinary literature. Based on these we argue that, first, lock-in and sub-optimality help to identify processes as being subject to path dependency (see Section 2.1). If a process did not feature these *characteristics*, we would not assume that path dependency is at play and, thus, would not choose this process as an object of path dependency research. Second, self-reinforcement, contingency and initial situation are factors that, at a particular moment in time, interact in a way that creates path dependencies and makes one pathway prevail over other alternatives (see Section 2.2). An analysis of these *conditions* helps us to understand why and how path dependencies have occurred and how they affect the process in question.

2.1. Lock-in and sub-optimality

Lock-in occurs if a process enters a state of unchanging, persistent outcomes (Arthur, 1989). In economics and technology-focused definition, lock-in means that there is no or little chance of endogenous change (Vergne and Durand, 2010). From an institutional point of view, lock-in is a phase of stability characterized by, at most, minor and incremental change. However, in practice absolute lock-in is rare (North, 1990).

How path dependency can be overcome, (i.e. how paths can be changed) has received increasing attention among sociological and political science scholars adopting the path dependency concept. Arthur (1996) indicates that any technology has a natural end, as technologies come in waves. Similarly, Pierson (2000a) points out that change is "bounded" until new conditions erode or swamp the mechanisms of reproduction that, until then, have generated continuity. According to literature on policy processes and institutional change, drivers of change could be institutional entrepreneurship, institutional work, or everyday agency (Abdelnour et al., 2017; Battilana et al., 2009; Dimaggio, 1988; Lawrence et al., 2011; McMichael et al., 2019).

In more recent literature, path dependency is often described according to the absence of exogenous shocks (Vergne and Durand, 2010), which suggests that in a path-dependent state, a change of trajectory cannot be achieved from within. However, if a shock is understood as something that breaks path dependency, we should, in turn, ask if there are ineffective shocks that do neither result in change nor even cement lock-in. If ineffective shocks exist, lock-in cannot be defined solely through the absence of any exogenous shock. Otherwise, we have to distinguish shocks from contingent events (see below).

Lock-in appears to inhibit change if the trajectories created fall short of achieving stated targets, in other words, if they lead to sub-optimal

outcomes. Early literature on path dependency considers sub-optimality with respect to the effectiveness of a technology, namely, does technology cause disproportionate costs and efforts in relation to the desired level of benefits? For example, the Microsoft Disk Operating System (MS-DOS) was not the optimal system in the 1980s, but became locked in due to the available complementary soft- and hardware and IBM's established relationships with business communities (Gandal et al., 1999). The question of (sub-)optimality is more difficult to answer with respect to public policy, and it is only marginally – if at all – addressed in discussions regarding the path dependency of institutions. Judging a trajectory as sub-optimal or inefficient requires there to be a counterfactual reference as to what is considered optimal (e.g. a policy target to be reached) or efficient (e.g. a given ratio between costs and benefits). This is difficult in case where policies are frequently not attached to an evaluation logic that links measures with specific goals. Moreover, it implies that path dependency may also apply to processes that are considered positive by some, and where lock-in is welcomed.

2.2. Self-reinforcement, contingent events, and initial situation

Self-reinforcing mechanisms lie at the heart of most theorizing on path dependency. Self-reinforcement, which is labeled in the literature as increasing returns (Arthur, 1990) or positive feedback, ensures the continuity of chosen paths. In the path dependency literature, self-reinforcing mechanisms are usually explained in the context of technological innovation. Scientists have proposed a variety of frequently overlapping and intersecting mechanisms leading to self-reinforcement. Among these are high up-front costs combined with economies of scale (Arthur, 1996; Arthur et al., 1986; David, 1985), or learning effects on both the demand and supply side (Arthur, 1989, p. 19). Other system scale economies also create self-reinforcing dynamics, such as economies of agglomeration, which describe the effect of a successful business attracting more businesses to a location (Arthur et al., 1986), and demand side economies of scale or network externalities (Arthur, 1996; David, 1985; North, 1990), which imply that additional users increase the worth of a product or technology. Adaptive expectations describe past successes of a technology or product that lead consumers to stick with it and believe in its future success (Arthur et al., 1986). Finally, coordination effects come into play when the widespread use of a product or technology increases the attractiveness and probability of creating related products and technologies (Arthur, 1990). Similarly, interdependencies/technical interrelatedness (David, 1985), describe the phenomenon whereby a product is better established if there are more linkages between associated product components and also between competencies of product users.

Although these examples usually refer to technological changes, North (1990) highlights that they also apply to institutions or systems of institutions that reinforce or complement each other. According to Pierson (2000a, p. 257), mechanisms of self-reinforcement are also relevant in politics because of "(1) the central role of collective action; (2) the high density of institutions; (3) the possibilities for using political authority to enhance asymmetries of power; and (4) its intrinsic complexity and capacity." Nevertheless, self-reinforcement plays out differently in the political context than in the economic context because politics lack efficiency-enhancing mechanisms of competition and learning, political actors have a much shorter time horizon, and political institutions have a strong status quo bias in general (Pierson, 2000a). All these factors increase the difficulty of reversing a chosen path.

Self-reinforcing mechanisms may bridge path dependency theory with the debate on institutional barriers to adaptation. Barriers typically arise from complex actor constellations within rigid governance arrangements such as ingrained rules and norms, incorrect or incomplete knowledge, vested interests and competing agendas, unclear institutional roles, or lack of policy guidance to manage restricted resources (Wise et al., 2014; Werners et al., 2021). Due to institutional barriers, adaptation measures miss opportunities, are postponed, downgraded, or not implemented at all – in other words, they lead to sub-optimal outcomes (Moser and Ekstrom, 2010). The barriers literature has compiled extensive shopping lists of barriers (Adamson et al., 2018; Wise et al., 2014); self-reinforcing mechanisms detail the processes whereby market participants or institutions interact and may therefore may help in structuring and explaining why specific institutional barriers are present in specific contexts.

For many scholars, contingency is a crucial condition of path dependency because it distinguishes path dependency from the generic "history matters" argument (Vergne and Durand, 2010). A contingent event is the point of origin of path dependency, i.e. a specific situation at a specific moment in time that kicks off a narrow set of problem-solving strategies which are maintained, refined but not relinquished over the coming years. The usual line of argumentation is that contingent events, or rather a series of contingent (or chance) events, have more effect on the path taken than the initial situation (Vergne and Durand, 2010). Accordingly, the aftermath of contingent events is more important for understanding the future trajectory of an ongoing path than the initial situation and the identification of path dependency involves "showing how these events are themselves contingent occurrences that cannot be explained on the basis of prior historical conditions" (Mahoney 2000, p. 507f).

However, scholars are still struggling to explain when an event is contingent. Mahoney (2000, p. 514) explains: "In the actual practice of research, social analysts will consider an event to be contingent when its explanation appears to fall outside of existing scientific theory. For example […] too specific to be accommodated by prevailing social theories […] and large, seemingly random processes such as natural disasters or sudden market fluctuations." The author points out that according to some studies an event being contingent is not necessarily the same as an event being truly random and without antecedent causes. Accordingly, Vergne and Durand (2010, p. 755) summarize it as "unpredictable, non-purposive, and seemingly random." This creates difficulties for its verification and falsification, simply because contingency cannot be proven independently of preceding theoretical assumptions (Mahoney, 2000).

In practice, it is plausible to operationalize contingent events as decisions made as a consequence of circumstances that are unusual, surprising for the planning process and often not anticipated in that particular organizational, governance, and institutional setting–as compared to the explanatory capacity of a theory or discipline. For instance, FRM often builds on the information of the status quo risk assessment and underrates the strategic perspectives of uncertain future developments and rare extreme events (Clar et al., 2021; Hutter, 2016; Nordbeck et al., 2019). However, for the purposes of outlining the conditions of path dependency, the reactions to a contingent event seem more relevant than the reasons why this event occurs because these reactions set the boundaries for the ensuing path development and trigger path dependency.

Nonetheless, although contingent events are said to overrule initial situations, we have to acknowledge that some authors also place major emphasis on the role of the latter (Baum and Silverman, 2013; Liebowitz and Margolis, 1995). Thelen (1999, p. 385), for example, criticizes David's (1985) approach to path dependency as too contingent – because institutions will never emerge on a clean slate. At the same time, she considers it too deterministic – because the initial situation unrealistically constrains further developments. Accordingly, for now there is no solution how particular conditions are related to contingent events, and how they are related to the subsequent reproduction and feedback mechanisms on which institutions rest and are sustained (Thelen, 1999). At least, scholars agree that further knowledge about how institutions were constructed would "provide insights into how they might come apart" (Thelen, 1999, p. 400; see also: Pierson, 2000b, p. 263).

3. Path dependency in the context of FRM

To gain a better grasp of the path dependency concept, we specify and illustrate the characteristics and conditions of path dependency for the FRM context. In FRM, path dependency may exist for institutions and policies, as well as for the measures used (van Buuren et al., 2016); we thus consider both technological and institutional perspectives.

3.1. Lock-in

In FRM, lock-in has been most frequently described in the context of hard management measures (i.e. grey infrastructure) such as dams and dykes (Wesselink, 2016). In this case, the length of the lock-in can be determined by the lifetime of infrastructure, which can be 40–80 years depending on the materials used (Hübl and Kraus, 2004), and it can also potentially be extended by refurbishments and reinvestments. Research has shown that lock-in does not have to be limited to technological aspects and can span many more decades if self-reinforcing mechanisms and incumbent-actor coalitions are at work (e.g. Parsons et al., 2019; Tellman et al., 2018). Lock-in in this context could be tied to depreciation processes, for example to the turnover of mindsets and ideas by employee fluctuation in incumbent institutions, to infrastructure lifetime, or to (re-)occurrence intervals of contingent events such as reorientation of political agendas by legislative periods, or to return periods of severe flood disasters.

Extreme flood events typically appear as exogenous shocks that may break or at least weaken path dependency at the regional or national level. Flood events might open up a policy window to change the currently prevailing management path (Birkmann et al., 2010; Friedman et al., 2019). Such a policy window might be open for a short time period (Sword-Daniels et al., 2015) or over several years, such as in the case of planned relocation from flood-risk zones in Austria (Thaler et al., 2020). To take this opportunity, however, policy makers and stakeholders need to be able to recognize and understand corresponding signals based on experiences of previous debates (Penning-Rowsell et al., 2006; Thaler et al., 2020).

Bloemen et al. (2018) suggest that change needs to be transformative to break path dependencies, and that incremental change is indeed conducive to lock-in. Thus, as a negative proof of path dependency, lock-in may be falsified by identifying a non-random, deliberate, transformative decision that deviates from previous patterns but successfully contributes to the overall policy goal. For instance, if a large community in a region that has pervasively relied on building levees, is relocated from a flood risk area instead of yet another levee being built, the assumption of lock-in cannot be sustained. There may be instances when incremental change does not always lead to lock-in, but that continuous transformation is possible (Termeer et al., 2017).

3.2. Sub-optimality

In FRM, what is considered as sub-optimal needs to be assessed as the deficiency in a protection target or in the tolerable level of residual risk (Rauter et al., 2020). If decision-makers do not commit to an explicit target or level, we cannot ascertain whether the sub-optimality criterion of path dependency applies. Cost-efficiency and cost-effectiveness may still be key criteria on which to judge the optimality of a path; calls to use cost-benefit-analysis in APA support this assumption (e.g. Bloemen et al., 2018; Haasnoot et al., 2019). As with sub-optimality, using inefficiency as a criterion for path dependency requires a predefined ratio of costs to benefits to be achieved – at the very least, benefits should balance costs. However, a comprehensive perspective on efficiency should not just include monetary aspects such as the value of exposed assets or construction costs, but account, too, for intangible aspects such as disruption of livelihoods or social support (Rufat et al., 2015). Questions of optimality could be extended to how issues of distributional and procedural justice are considered. Multiple criteria might include economic effectiveness, legitimacy, accountability, social justice, social capacity, physical and social vulnerability, technical feasibility, or ability to implement (Alexander et al., 2016; Kuhlicke et al., 2011; Thaler and Hartmann, 2016).

Absence of clearly defined targets for FRM measures is not uncommon. For example, during the post-disaster period, actors might not agree if the goal should be to return to the pre-disaster state as fast as possible or whether a "slow" and transformative recovery process should be initiated (Mika and Kelman, 2020). Especially in cases of conflicting interests and an unclear distribution of responsibilities among different actors, stakeholders, and citizens, this might easily result in sub-optimal outcomes (Rauter et al., 2020).

3.3. Contingent events and initial situation

In the FRM context, contingent events and initial situations have not been addressed as path dependency research, but can be revealed through historical shifts in FRM paradigms. Until the 1970s the focus of FRM was very much on land drainage, before it shifted to the protection of urban areas, and then to integrated, strategic flood defense systems, including a stronger focus on living with floods (Johnson and Priest, 2008; Penning-Rowsell and Johnson, 2015). Since 2007, we have been observing the last shift towards flood risk governance or flood risk resilience (Albright, 2011; Klijn et al., 2013; Nye et al., 2011; Parsons et al., 2019; Penning-Rowsell and Johnson, 2015; Thaler and Priest, 2014). These policy changes were triggered by very different but nonetheless interacting factors, not necessarily flood events but also evolving discourses and political debates, as well as broader socioeconomic developments. For instance, land drainage in the United Kingdom became a key priority in response to the food shortage during World War One (Brown and Damery, 2002; Scrase and Sheate, 2005). The shift towards urban areas and the use of new risk management strategies, such as land use planning, was mainly related to structural changes in agricultural food production (Escobar and Demeritt, 2014; Fuchs et al., 2020). The transition towards a more integrated FRM at the beginning of the 1990s across Europe was driven largely by a series of extreme flood events, such as the 1993/1994 and 1995 floods in the Netherlands and the 2002 floods in Germany and Austria (Hartmann, 2011; Kaufmann, 2018; Klijn et al., 2013; Klijn et al., 2008; Nye et al., 2011). Apart from these obvious hazard events, the underlying drivers contributing to the extent of disasters like these were socioeconomic trends such as changes in socio-demographics, individual consumption, and increasing wealth and assets (Sadoff et al., 2015; Winkler et al., 2021).

Thus, a contingent event in the FRM context could be defined as a flood event that overstretches current risk management capabilities and therefore brings about a shift in institutional paradigms and responsibilities (Kuhlicke et al., 2020). Institutional paradigms and responsibilities thus change over time and enforce new arrangements and new power relationship settings, such as FRM being organized quite specifically within a river basin at a catchment level instead of a "local" perspective of settlements being relocated (Penning-Rowsell and Johnson, 2015; Thaler et al., 2017). This would mean that in any given decision context, contingent events could be identified through reconstruction of past events based on available documentation, and/or through key informant interviews. Multiple stream theory (Kingdon, 2010; Kingdon, 1984) might provide a useful categorization of contingent events into: (1) a rare flood event as part of the problem stream, (2) new risk reduction measures being conceived as part of the policy stream, or (3) political changes caused, for example, by elections as part of the political stream.

The main challenge for the operationalization of contingency and initial situation is to identify what variables are relevant, such as past flood events, new legal enforcement, innovations, or socio-political change, for example, the shift from being a welfare state towards neoliberal government. This requires scholars to look backwards and identify causal relationships that help us to understand why contingent

events stand out from a simple continuation of the initial situation and pave the way for self-reinforcing mechanisms and lock-ins (Wise et al., 2014). For example, authors such as Fazey et al. (2016) and (Fischer (2018), explored how 'mapping' historical pathways can help participants to appreciate the implications of their decisions for others and for future possibilities (Bosomworth and Gaillard, 2019). Moreover, it is important not to construe or over-interpret a particular moment or constellation as the decisive point only to narrow down the analysis period and, consequently, disregard everything that caused the situation in question to develop. The identification and analysis of relevant developments within their specific social, economic, and political context allow us to understand various forms of social or institutional innovations in terms of societal transformation across the globe (Nyseth and Hamdouch, 2019; Scott-Cato and Hillier, 2010). In this context reference frameworks to transparently cover framework conditions are required, such as that provided by the five capitals approach (Thaler and Seebauer, 2019), Ostrom's socio-ecological-systems (Ostrom, 2007), or technological innovation systems (Bergek et al., 2008). Ultimately, this shows how important it is to understand what conditions lead to path dependency. whereas, whether an event is contingent remains secondary.

3.4. Self-reinforcing mechanisms

In the FRM context, self-reinforcing mechanisms have been at the heart of more detailed inquiries into path dependency. Wiering et al. (2017) and Parsons et al. (2019) stated that the initial situation and contingent events need to be considered in order to understand how path dependency originates. However, neither concept can explain why this path is sustained. In Table 1 we provide an overview of self-reinforcing mechanisms with the intention of mapping the scope of mechanisms that are potentially relevant for FRM. In the FRM realm, self-reinforcing mechanisms are characteristic of the "classical" decision to implement structural measures (such as dams) instead of other innovative solutions, like nature-based solutions. The levee effect, too, where the construction of protection infrastructure such as dams encourages an accumulation of assets in the new protected area is a typical example of a self-reinforcing mechanism (Baldassarre et al., 2015; Collenteur et al., 2015; White, 1945).

To some extent, mechanisms developed for technological innovation can be translated into institutional contexts of path dependency. However, many institutional factors influencing path dependency are difficult to establish as clear mechanisms. So as not to neglect those components that potentially enhance path dependency – most importantly political authority/power asymmetries, (exceptionally) dense institutions, collective goods/action, (exceptional) complexity – we consider these as distinct conditions to be explored, where mechanisms might be deduced from empirical studies and serve to build theories in the future.

Self-reinforcing mechanisms induce positive feedback and therefore may apply to both negative or positive paths with less or more optimal and efficient outcomes. In column three of Table 1, we provide examples of both. We recognize that such a distinction is inevitably arbitrary, comparable to the characteristic of sub-optimality, and that any such distinction is context-specific and depends on the problem framing in any specific case. However, a classification of negative and positive paths can stimulate discussion about whether or not path dependency can also be beneficial, for instance, if it aligns with desirable goals and outcomes.

4. Integrating path dependency in an adaptation pathways approach

Traditionally, the path dependency concept has been applied to analyze past developments. APAs however, are most often forward-looking. The effort itself (i.e. adopting an APA to consider alternative

Table 1
Self-reinforcing mechanisms. Generic and FRM specific descriptions.

Self-reinforcing mechanism	Generic specification in the context of technology and/or policy	Operationalization for flood risk management
Technology-based mechanisms		
High up-front or fixed costs and supply side economies of scale (Arthur, 1996)	Development/ installation of a technology requires high initial investments (high sunk cost investment risk), that with increased production pays off with decreasing per unit costs.	+ The longer structural measures are in operation the more efficient they become from a cost-benefit perspective. As soon as construction costs are amortized, they provide a net benefit until the end of their lifetime. Designing structural measures for longevity and easy maintenance/ upgrading yields more benefits in the long run. - Many water authorities maintain a standing stock of construction machinery and workforce of qualified craftspeople. Machinery and workforce are tailored to standard structures, which makes them cheaper than innovative projects.
Learning effects (quasi-irreversibility of investment as seen in David 1985)	Learning effects may occur both on the supply and the demand side, respectively. Here learning effects refer to learning by doing or by using, which gradually improves the quality of a product (thus making it more attractive to its users). At the same time users gain experience in using a certain technology, which makes it attractive to keep using rather than switching to an alternative. These effects are also referred to as single-loop learning, which is primarily focused on improving the efficiency of action (Pahl-Wostl, 2009; Pelling et al., 2008).	+ Governments have acquired knowledge on infrastructure projects (i.e. engineering solutions) and stick to that knowledge. Expertise, routine, qualified craftspeople, and established construction designs encourage the replication of standard structures. Hydrological models or ecological impact assessments have been calibrated to standard structures and provide reliable estimates. - Innovative strategies are easily rejected, because they cannot compete with the level of sophistication and reliability featured by standard structures. - Governments avoid innovative strategies because of the additional learning effort attached to resolving legal restrictions, administrative responsibilities or public acceptance. Instead, they rely on readily available, well-tested options.
Adaptive expectations (social expectation) (Arthur, 1989)	Adaptive expectations refer to the assumption that actors base future decisions on recently gained information or recent past events. This	+ Standard structural measures did succeed in decreasing flood damage over the past decades. - Risk assessment is extrapolating the status

(continued on next page)

Table 1 (*continued*)

Self-reinforcing mechanism	Generic specification in the context of technology and/or policy	Operationalization for flood risk management
	means that if a technology has experienced recent successes, actors tend to believe that it will continue to be successful and stick with it.	quo: assuming that hazard and exposure will remain as they are; making oversimplified assumptions on climate impacts or socio-economic developments; making insufficient acknowledgment of uncertainties in future risk projections; preventing the last flood event (similar to "fighting the last war").
Network externalities/ effects (demand side economies of scale) (Arthur, 1990, 1989; North, 1990)	The more a technology is used by others, the more attractive it becomes (e.g. communication technology, like the telephone and social media platforms)	+ Experiences with standard structures can be transferred to other locations, resulting in these measures showing less uncertainty about the level of risk reduction, maintenance costs, etc. - Transfer by mirror replication overlooks the value of local context. - The levee effect increases potential damage; structural measures already in existence need to be extended (marginal costs). - Vulnerability of waterfront residents is increasing because increased prosperity leads to the upgrading of protection measures. - Small municipal budgets are overburdened by maintenance costs (e.g. dredging retention basins) which leaves little disposable budget for alternative measures.
Coordination effects (Arthur, 1990, 1989; North, 1990)	The more widespread a technology is, the more attractive it is to produce related services and products, infrastructure, and even policies and institutions.	+ Role models: specific types of action are perpetuated as neighboring municipalities borrow expertise, as well as learn from and mimic each other's actions, such as multi-functional protection measures. + Emergence of engineering consultancies specializing in technical solutions, in response to increasing demand. - A widespread regime of standard structural measures makes it hard for innovative measures to go beyond sporadic pilot implementations as technical planners, construction companies or regulatory bodies have to adapt established procedures.

Table 1 (*continued*)

Self-reinforcing mechanism	Generic specification in the context of technology and/or policy	Operationalization for flood risk management
Interdependencies/ complementarity (David, 1985; North, 2018)	The more technologies and their components depend on each other, the more embedded they become and the harder to change.	+ Standard technical mitigation measures are well-tested and well-known in terms of efficiency in risk reduction, thus, their reciprocal and complementary effects can be leveraged in supra-regional, catchment-wide planning. - Structural measures often increase the damage potential, because of the construction of new buildings behind, for example, a dam, which leads to more structural measures in the regions. - In upstream/ downstream cooperation, the measures that already exist or are constructed first, pre-determine which other measures are possible.
Institution-based mechanisms *(Mahoney, 2000; Pierson, 2000a)*		
Political authority (actor coalitions)	Groups of actors with similar interests, who are in possession of power and resources, enabling them to maintain a path suitable to their interest.	+ Actor coalitions show a high degree of accordance and agreement about FRM strategy, which facilitates and streamlines the planning and implementation process. - Institutional capture: grown relationships and "revolving doors" job changes between administrative offices aligns the views of different actors and encourages narrow-mindedness. - Institutional assignment of functions, duties, and budgets leads to reproduction of the same old problem solving strategies, in particular, if higher governance levels provide budgets and therefore set the rules (e.g., which return period serve as design reference).
Institutional density	Once a path is deeply institutionally embedded, it is difficult to disentangle and change that path.	+ High stability in planning and management processes increases the pace from conception to implementation. - A wide range of different organizations involved in the FRM hinders radical change, as each organization tends to defend its duties, power and standing.

(*continued on next page*)

Table 1 (*continued*)

Self-reinforcing mechanism	Generic specification in the context of technology and/or policy	Operationalization for flood risk management
Collective goods/action	If a path is related to a collective good or collective action, processes are more prone to path dependency because it requires detailed rules on multi-actor collaboration, which take a long time to negotiate and establish, and are thus hard to change.	+ Involvement of multiple actors increases democratic legitimacy and representation of social justice and leads to enduring public support. - Umbrella organizations (e.g., an inter-municipal flood council) function as token activities, decisions are postponed in task force roundtables. - Diffusion of responsibility between multiple actors: single actors are encouraged to stay in the background instead of stepping forward as first movers.

+ Reinforcing more optimal and more efficient outcomes; − reinforcing less optimal and less efficient outcomes.

pathways) implies prevention of potential path dependencies. However, to date it has remained unclear as to what "path dependency" is and how exactly it could be anticipated, established or overcome. Wise et al. (2014) proposed looking at historic developments to avoid path dependencies. Haasnoot et al. (2019) suggest factoring in the costs and benefits when transferring to another path, thereby enabling endogenous change by making the pros and cons of all alternatives at each process stage transparent. According to our assessment, however, this fails to realize the full potential of considering path dependency in an APA. Having outlined and operationalized path dependency in the previous sections, we now show step-by-step how different elements of path dependency can be addressed throughout an APA.

We have adapted and expanded the process of developing and monitoring adaptation pathways from Haasnoot et al. (2013) to incorporate the multiple stakeholder dimension as well as the potential for transformation, as shown in Fig. 1. We rearranged the steps in an APA to also fit stakeholder-oriented and transformation-oriented approaches. This means that step 1 of such a process would consist of framing problems and objectives. Step 2 would then be a description and analysis of the current situation with particular focus on the institutional context. In contrast to the original figure by Haasnoot et al. (2013), we do not emphasize the specific method of transient scenarios to explicitly open up space for a wide variety of qualitative and quantitative methods as suggested in different APAs that can be used at steps 2–5 to develop actions and pathways. Fig. 1 also highlights the importance of a backward-looking perspective spanning steps 1 and 2 (e.g. Wise et al., 2014; Parsons et al., 2019). In particular, account needs to be taken of historic development in order to understand how the current problem evolved from the root causes of vulnerabilities and socio-economic and demographic developments in the region. These pieces of information provide the starting point for re-orienting to a more optimal and more efficient adaptation pathway trajectory. Transformational change to overcome lock-in may be achieved at two different phases of the APA cycle: In steps 3–5, by introducing new and innovative actions as constitutive elements of pathways; or in steps 9 and 10, by monitoring, evaluating and if necessary revising pathways after strategic plans meet the real world.

Fig. 1 shows this ten-step design process for adaptation pathways, and seven distinct entry points for path dependency considerations at different steps, which we defined based on the operationalization in Section 3. We describe each entry point in the following. Table 2 presents examples of how to operationalize these entry points and hence of the concept of path dependency for APA in the context of FRM. Entry points II-IV refer to self-reinforcement, contingent events and initial situation as the conditions of path dependency (see Section 2.2) and therefore indicate starting points for understanding and, by means of dedicated measures, unlocking path dependency. Refinement, specification, and testing however remains subject to further empirical studies.

Entry point I "define sub-optimality": step 1 in an APA, as defined here, refers to problem framing, and should entail reaching a definition of what optimal or sub-optimal means in a respective case. As noted

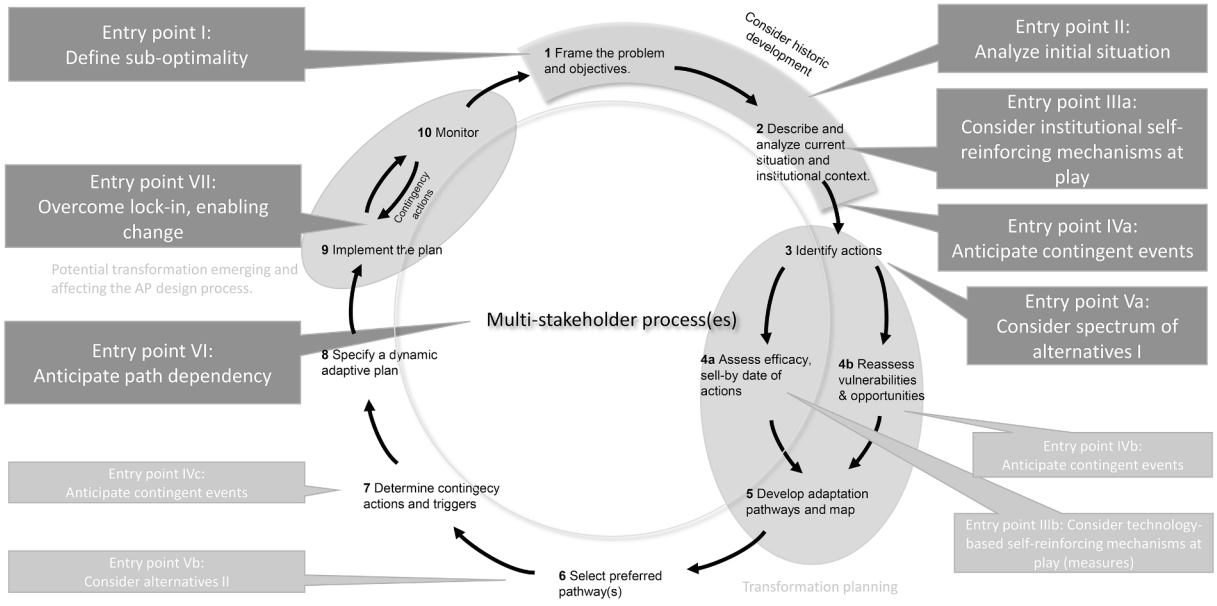

Fig. 1. Seven entry points for explicitly considering path dependency when *designing adaptation pathways*. The design process is adapted from Haasnoot et al. (2013) and complemented to consider that adaptation pathways ideally include a historical or backward looking perspective (grey arc), are often designed in multi-stakeholder processes (center circle), and that they might aim to achieve transformational change (grey bubbles). In practice, an APA process might emphasize different steps and might also not encompass all steps shown in this figure.

Table 2
Entry points. Examples for operationalization for FRM.

Entry points	Operationalization for flood risk management	Examples for implementation
1. Define sub-optimality	Assess the "optimal" risk reduction target based on the as low as reasonably practicable principle. The definition of the optimal level should be based on cost-benefit assessment as well as stakeholder interests and needs. With the increasing systemic complexity of decision and planning situations, optimality may have to be reconsidered in favor of necessary redundancies, low-regret options, and sufficiency (UNDRR 2019)	• Infer (implicit) protection goals from strategies and planning documents (e.g., residual risk tolerated in previous decisions, return periods stated in risk maps) • Identify input/output variables in cost-benefit assessment or other decision-support tools • Specify policy targets in visioning workshops
2. Analyze initial situation	Define and describe the initial situation for a path dependent development in terms of the baseline assessment for developing adaptation pathways, taking the already existing FRM strategy in the selected area as starting point.	• Compile a historical timeline of flood events and measures from policy documents, newspapers and event databases • Map institutions and stakeholders and their respective interrelations • Identify hard caps of the decision space (e.g. available land and budget, prior customary rights)
3. Consider self-reinforcing mechanisms at play	(a) Institution-based mechanisms: Assess the current institutional framework and modes of governance in FRM. Policy entrepreneurs play an important role in recognizing leverage points and loopholes in current funding and legislation. (b) Technology-based mechanisms: Assess the implementation of various risk reduction strategies; including the assessment of residual risk for the selected area. Take into account structural and, possibly less apparent, non-structural measures.	• Conduct semi-structured expert interviews with political and administrative representatives at the regional and local level • Validate interviewee responses from multiple stakeholder perspectives, interview active as well as retired officials • Map administrative procedures in planning, financing and approval of measures • Map the formal and informal distribution of responsibility between institutions • Check the reference measures to which hydrological models are calibrated • Check registries of existing measures and maintenance activities
4. Anticipate contingent events	Define the contingent events that might kick-off a path dependent development; (a) Consider historical socioeconomic and land use development with the aim of assessing the risk level for the selected area (including assessment of process magnitude and frequency, social and physical vulnerability as well as exposure). (b) Consider adaptation tipping points when a chosen path fails to meet its objective. The assessment foresees the assessment of the usual actions in FRM. (c) (c) Define the contingency planning after identifying options and preferred pathways. The assessment includes possible changes in the regions, including possible impacts of a warmer climate, demographic and land use changes.	• Reconstruct historical socio-economic and land use development and project these developments to regional scenarios • Assess exposure and physical/social vulnerability of non-/residential properties and people • Determine sell-by-dates of existing measures • Define an additional layer of decision points which cater to possible contingent events
5. Consider spectrum of alternatives	Assess alternative pathways for risk reduction measures and their possible effects, including future developments, such as climate change, land use change, or demographic change.	• Compare non-/structural measures by efficacy, costs, sell-by date and flexibility to be adapted to changing conditions • Conduct qualitative or quantitative expert elicitation to assess side-effects, informal aspects and barriers to implementation of specific measures • Analyse reciprocal or complementary effects of combinations or sequences of measures
6. Anticipate path dependency	Develop and jointly implement strategic and innovative bottom-up risk reduction concepts, such as natural flood management on privately owned-land, multi-functional risk reduction measures etc. to improve the capacity to anticipate and overcome path dependencies.	• Conduct a transdisciplinary and multi-stakeholder co-production process using participatory modeling and scenario exercises • Develop actor coalitions and promote new policy entrepreneurs
7. Overcome lock-in, enable change	Monitor effort and the potential need for implementing contingency actions. This step actively creates opportunities for internal change, which is important for overcoming lock-in situations and thus a key element in terms of avoiding path dependencies.	• Conduct semi-structured expert interviews to track internal change • Establish discussion formats and workspaces which transcend origin institutions and hierarchies

above, sub-optimality does not necessarily equal non-efficiency, but it needs to be defined for each individual planning problem. Here it is also important to explore the actual decision to apply an APA and the implications of that decision for the design of the remainder of the process (see also Werners et al., 2021).

Entry point II "analyzing initial situation" coincides with the analysis of the current situation and institutional context (Step 2), and is crucial for the identification of looming path dependencies such as in Adamson et al. (2018) and Parsons et al. (2019). Neither APA nor the path dependency concept provide guidance on which dimensions of the current or initial situation should be analyzed specifically, for example, with respect to institutional frameworks, existing FRM strategy or legal restrictions which set the boundaries for previous and future pathways. Using existing frameworks such as Ostrom's social-ecological-systems, the five capitals approach, or technological innovation systems can be useful for a structured analysis.

Entry point III "consider self-reinforcing mechanisms": step 2 in the APA allows the self-reinforcing institutional mechanisms at play to be understood, as they may need to be addressed (entry point IIIa). This

will be particularly successful if these mechanisms are traced in historical decisions. In step 4 of the APA, technology-related self-reinforcing mechanisms can be considered (entry point IIIb). Analyzing self-reinforcing mechanisms in an APA probably requires the most additional effort. It is not, however, less relevant, as unidentified self-reinforcing mechanisms operating in the background may undermine or even derail alternative pathways and may incur additional transfer costs when it becomes necessary to switch to an alternative pathway. The descriptions in Table 1 offer several aspects to look for when considering which mechanisms might be at play. Overall, search for institution-based mechanisms should look for the density of institutions necessary for effectively implementing a path, coalitions which sustain a certain path, and whether collective action is required to implement and maintain a certain path. Search for technology-based mechanisms should elicit how the upfront, maintenance and decommissioning costs of single measures result from cross-measure effects such as learning, coordination or interdependency/complementarity.

Entry point IV "anticipate contingent events" can be carried out as early as in step 2 of an APA (entry point IVa in Fig. 1), at steps 4a/b (entry point IVb), and again during step 7 (entry point IVc). Looking at the historical development in e.g. social stratification or land use reveals previous contingent events. At steps 4a/b the analysis of adaptation tipping points indicates under which conditions a chosen path fails to meet its objective (Haasnoot et al., 2012). A contingent event such as the end of the projected lifetime of a measure is easy to anticipate. However, other contingent events may be not as easy to anticipate and thus much more difficult to visualize in an adaptation pathway map. Multi-stakeholder scenario exercises may sensitize decision makers and compile a more comprehensive set of contingencies early on (Haasnoot et al., 2012). Ultimately, by definition, it is not possible to exhaustively anticipate contingent events. However, during step 7 contingency planning can be revisited after having identified options and preferred pathways. At this step, foresight should focus on contingent events that lie outside of the existing institutional design and policy frameworks.

Entry point V "consider the spectrum of alternatives": in step 3 of an APA adaptation actions are identified; in step 6 preferred pathways as combinations of actions are selected. Both steps should connect to the framing of problem and objectives undertaken in step 1. Taking into account a broader set of alternatives, which even transcend current institutional boundaries, avoids falling back to well-known quick fixes. Actively considering and visualizing the full spectrum of alternatives is in itself an activity that potentially avoids path dependencies.

Entry point VI "anticipate path dependency" taps into multi-stakeholder involvement, co-production and transdisciplinary research; this process has been completely absent from early work on path dependency. As indicated in Fig. 1, stakeholder involvement can happen throughout the entire process, or more focused at individual steps. There is no clear prescription for APA on how to involve stakeholders, but involving a diverse scope of key actors may facilitate identifying and addressing institution-based self-reinforcing mechanisms.

The final entry point VII "overcome lock-in/enable change" directs attention to the implementation stage. Ultimately, this is where the overcoming of lock-in and the enabling of change manifests within the current FRM strategy in a specific geographical context. This crucial entry point builds on and integrates the decisions taken at earlier steps in the APA. Leveraging this entry point would require overcoming incremental single-loop learning, which is often prevalent in national FRM strategies, by fostering social and societal learning that leads to double- and triple-loop learning that challenge underlying mental models and question deeply held underlying principles, respectively (Pahl-Wostl, 2009; Pelling et al., 2008) Again, this transformation would ideally happen through a multi-stakeholder co-creation approach. The current state of research and practice hardly documents monitoring and evaluation of accomplished and implemented APAs (Werners et al., 2021). However, collating experiences to revise objectives, thereby returning to the APA step 1, seems critical for achieving transformational, enduring change.

5. Discussion and conclusions

How future flood risk will develop is highly uncertain due to the complex interaction of climatic drivers – both natural variability and anthropogenic climate change – and the socioeconomic processes related to the exposure and vulnerability of populations. Any current decisions with respect to future flooding have to account for this uncertainty, and thereby enable future decision-making that is flexible enough to accommodate changing circumstances. However, past decisions may also limit or enable FRM decisions. We argue that, to improve the basis of information for future FRM decision-making, it is important to evaluate contingent events in the past and the subsequent self-reinforcing mechanisms leading to sub-optimal or inefficient outcomes. In this paper, we provide a baseline for assessing whether or not path dependency is at work in specific FRM contexts through the analysis of characteristics and conditions of path dependency. More specifically, we link two strands of literature, APAs and the path dependency concept. Until now, these have been linked superficially at best, leaving a great deal of untapped potential for comprehensively assessing path dependencies for FRM and other planning practices.

We find that APAs serve well to operationalize and encourage the understanding of path dependency in the context of FRM. In turn, the linking exercise presented here helps to improve the analytical value of APAs with respect to the anticipation of path dependencies. Our analysis suggests that the design and analytical process of APAs is well suited for easily incorporating all the characteristics and conditions of path dependency. This means that, with a minor additional effort, a comprehensive analysis of path dependencies can be achieved to enrich and improve the process of developing adaptation pathways. The operationalization of self-reinforcing mechanisms is particularly useful, as these may perpetuate potentially sub-optimal paths or maintain productive ones.

Path dependency is only one concept that contributes to giving APAs a better grounding in interdisciplinary theory. While it provides a useful entry point for critically discussing and expanding such approaches, complementary theoretical concepts would help unravel further complexities faced when analysing adaptation pathways. The backward-looking analysis of adaptation pathways allows us to understand why lock-in situations occured in the past. Understanding these long-term developments of decision-making arenas, where local adaptation policy evolves, expands our knowledge of decision-making processes in FRM, but likely also in other planning domains. Additional historical methods could be useful for expanding existing approaches (e.g. Adamson et al., 2018). The combination of past and future perspectives allows us to grasp how earlier decisions enabled or constrained later decisions and how they promote innovations in FRM. Moreover, adaptation pathways do not usually operate as independent trajectories but are linked to other policy trajectories, which might create parallel and interacting pathways. Path dependency as part of a dynamic systems approach provides interesting opportunities to improve, expand, and better operationalize the path dependency concept, particularly in the context of increasingly systemic and complex planning issues (e.g. Tellmann et al. (2018)). It is in these situations that aspects of path dependency need to be reconsidered. For example, optimality might have to be given up in favor of ideas of redundancy, low regrets, and sufficiency when planning for resilient adaptation pathways (UNDRR, 2019).

Building on the insights gained from exploring path dependencies in the FRM context, we suggest to apply this path dependency lens also in other research and practice applications of adaptation pathways, such as water scarcity/drought risk management, forest disturbance or landslides management. We expect that also within these fields the assessment of path dependencies and adaptation pathways are crucial to find

adequate responses to future global environmental changes.

CRediT authorship contribution statement

Susanne Hanger-Kopp: Conceptualization, Investigation, Writing – original draft, Writing - review & editing. **Thomas Thaler:** Writing - review & editing. **Sebastian Seebauer:** Writing - review & editing. **Thomas Schinko:** Writing - review & editing. **Christoph Clar:** Conceptualization, Investigation, Writing – original draft, Writing - review & editing.

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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