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Transformative mechanisms in decarbonization policies: a structured approach

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1. Overview

The transition to a low-carbon society should accelerate to avoid an increase in the temperatures above 1.5° to 2°C, and this is unlikely to occur without policy intervention (IPCC, 2022). Given the complexity of the problem, recent debates have increasingly pointed to the need of adopting a new, broader view on policy intervention (Weber and Rohracher, 2012; Hekkert et al., 2020). This entails a move beyond a single focus on economic competitiveness and growth and towards a focus on societal problems or “grand challenges”, leading to the emergence of the concept of transformative innovation policy (Schot and Steinmueller 2018; Dierks et al., 2019). This new rationale implies the consideration of a much broader range of policy objectives, targets and instruments, as well as the notion that a mix of policies needs to be deployed to achieve the desired goals (Rogge and Reichardt, 2016).

While this policy rationale has started to enter innovation policy agendas (European Parliament, 2022), it remains to be seen to what extent it is reflected in the actual policies being implemented (Casula, 2022; Rohracher et al., 2023).

The innovation policy literature has advanced conceptually at this level, discussing the nature of the problems that need to be addressed and proposing several dimensions along which policy could act in order to induce transformative effects (Weber and Rohracher, 2012; Schot and Steinmueller, 2018; Kuhlmann and Rip, 2018; Dierks et al., 2019). In some cases, this literature has also investigated empirically the case of particular policies, analyzing them in detail and assessing whether these potentially transformative mechanisms are considered, and which forms they assume, as well as which are the missing elements (e.g. Dierks et al., 2019; Casula et al., 2021; Molas-Gallart et al., 2021; Grillitsch et al., 2019; Bugge et al., 2017; Ghosh et al., 2021). These case studies are very relevant, because they provide us with a more in-depth understanding of the nature of policies with transformative potential. However, they do not enable us to have a perception of the extent to which these mechanisms are making their way into a wider set of policies, namely policies explicitly aiming at decarbonization.

This research addresses this gap by proposing literature derived mechanisms that are expected to introduce transformative effects in policies and investigating their presence in a broad set of decarbonization policies, from different world regions. For this, the paper draws on large database of policies compiled from the European Environment Agency (EEA) and the International Energy Agency (IEA) public policy databases, totaling over 3000 policies from Europe, USA, China and Japan. The goal is to understand whether transformative mechanisms are being introduced in current policies, which mechanisms or combinations of mechanisms prevail/are missing, and which sectors emerge as preferential targets, thus contributing to the debate on the formulation and implementation of transformative sustainable policies.

2. Method

2.1 Conceptual framework

In order to assess the transformative potential of current decarbonization policies we started by identifying policy features that are proposed in the literature as inducing transformative effects.

For this, we conducted a review of the stream of literature that introduced the new perspective to policy intervention, based on the awareness that existing policy approaches were insufficient to tackle major contemporary societal problems, such as climate change, that are complex, systemic and urgent (Mowery et al., 2010; Mazzucato, 2018; Schot and Steinmueller, 2018). Several lines of research proposed different approaches, supported by diverse (e.g., narrower or broader) views on innovation and change (Dierks et al., 2019), ranging from the re-adoption and reconfiguration of “mission-oriented policies” (Mazzucato,

2018) to more open-ended approaches generally labelled “transformative innovation policies” (Schot and Steinmueller, 2018). Despite the differences, these approaches share the fundamental view that solving these major societal problems, or “grand challenges”, entails economic and social transformations across several societal domains. This corresponds to an effective change in the nature of the problems being addressed by policy (Dierks et al., 2019), conferring policy a greater role in setting or shaping the direction of change (Webber and Rohrer, 2012), and introducing new requirements concerning goals, types of interveners and modes of intervention.

An extensive body of literature discusses these requirements, describing several features that can differentiate these “challenge-led” policies from more “traditional” policies (Haddad et al. 2022; Dierks, et al., 2019). For this research we selected a number of such features, which, according to the literature, may signal the purpose of addressing the complex nature of the (decarbonization) problem, by introducing some transformative effects in the policies.

The features selected are: to encourage experimentation; to engage a diversity of actors; to encompass activities of a variety of sectors; to involve multiscale coordination; to enable reflexivity. In addition, it was also considered that a mix of instruments may be required to implement them. This selection had into account the scope of this research – which intends to move beyond specific policy cases to a broad set of decarbonization policies – thus taking into consideration the fact that the presence of these features had to be empirically assessed from very generic descriptions of each individual policy.

Experimentation is described as critical given the complex and multidimensional nature of the problems and the uncertainty about the possible paths to follow, which calls for exploration and learning, in processes that should encompass a variety of concerned societal groups (Kuhlmann and Rip, 2018; Schot and Steinmueller, 2018; Sengers et al., 2016; Grillitsch et al., 2019; Molas-Gallart et al., 2021). Experimentation may range from trying new technologies and associated practices to learn about their potential to address a problem (Grillitsch et al., 2019) – which is closer to what is usually described as test and demonstration (Frishammar et al., 2015) – to broader processes of societal experimentation, which start from a problem and engage in explorative processes towards its solution, potentially involving a wider diversity of actors (Rogge, Pfluger and Geels, 2020). Experimentation requires not only interaction and collaboration across different fields, but also between different types of actors (Coenen et al., 2015; Grillitsch et al., 2019).

The engagement of a broad variety of actors is a central requirement, as problems are multi-sided, often covering several society domains. In particular, it is pointed out that it is relevant to consider new types of actors (besides industry and academia), which are not usually targeted by innovation policies, such as civil society actors, and involve them in broader partnerships that are more heterogeneous and inclusive (Howoldt and Borrás, 2022; Schot and Steinmueller, 2018). Attention has namely been called to the need of bringing-in actors from the demand side, in order to learn about their needs (Grillitsch et al., 2019); as well to consider the role played by intermediary organizations in enabling the engagement and successful interaction with the new types of actors (Kivimaa et al., 2019). This is important, on one hand, because perspectives on what is the problem and how it can be addressed vary across societal groups (Kuhlmann and Ripp, 2018; Coenen et al., 2015). On the other hand, it facilitates the acceptance and diffusion of solutions to the societal base these policies intend to reach (Mazzucato, 2018).

Problems are often cross-sectorial, encompassing and requiring the articulation of activities from a variety of sectors (Mazzucato, 2018; Schot and Steinmüller, 2018). This multi-sectoral dimension also has to be reflected in policies, which need to adopt a more transversal approach and/or bring different sectors to work together in new ways (Mazzucato, 2018). These namely entail acknowledging and stimulating interdependences between sectors (namely sectors that had limited previous connections) and enabling new recombination processes (Fontes et al., 2021; Janssen and Frenken, 2019).

As problems have a systemic nature, they are often embedded in complex institutional systems that span diverse spatial scales (Bunnell and Coe, 2001) – e.g. subnational, national, supranational. Thus, addressing them requires consideration of such multiscale and coordination between the different governance levels (Amantidou et al., 2014; Wanzenböck and Frenken, 2020; Steward, 2012).

Reflexivity refers to the need for continuous monitoring of progress towards the achievement of goals and targets, entailing the necessary adjustments resulting from learning processes; as well as adaptation to new challenges that may emerge along the change process and require questioning and reframing policy directions and instruments (Webber and Rohrer, 2012; Shott and Steinmueller, 2018; Molas-Gallart et al., 2021). These processes are critical given the tentative nature of transformation processes (Kuhlmann and Rip, 2018) and therefore they should be an integral part of policies, even if such nature may introduce particular difficulties in the monitoring and evaluation efforts (Kattel and Mazzucato, 2018).

Finally, the literature has pointed out that, due to the multidimensional and systemic nature of the problems and the requirements this generates for policies, combinations of different types of policy instruments are likely to be required (Borrás and Edquist, 2013; Wieczorek and Hekkert, 2012; Peñasco et al., 2021). In particular, a focus on experimentation and a need to involve and coordinate diverse constellations of actors from diverse societal domains may call for new types of policy instruments and/or more varied and complex sets of instruments (Howoldt and Borrás, 2022; Haddad et al., 2022).

The policy features selected as indicative of potential for inducing transformative effects are proposed as “transformative mechanisms” and their incidence and forms assumed in existing decarbonization policies are subsequently analyzed.

2.2 Empirical analysis

Data

The empirical analysis is based on data on decarbonization policies compiled from public databases. Data from European countries was obtained from the European Environment Agency (EEA) database on greenhouse gas policies and measures in Europe: <http://pam.apps.eea.europa.eu/>. This database contains policies and measures implemented, adopted or planned by European countries to reduce greenhouse gas emissions, that have been reported by European countries under the Governance of the Energy Union and Climate Action Regulation in 2021 (Germany and Iceland updated their submissions in 2022). Data was obtained on 2292 policies for 30 European countries, of which 26 are European Union members.

Data for the three other world regions included in the analysis – USA, China and Japan - was obtained from the International Energy Agency (IEA) Policies and Measures Database: <https://www.iea.org/policies>. This database contains information on past, existing or planned government policies and measures to reduce greenhouse gas emissions, improve energy efficiency and support the development and deployment of renewables and other clean energy technologies, which has been collected since 1999 from governments, IEA partner organizations and IEA analysis. Data was obtained on 562 policies for the USA, 279 for China and 153 for Japan.

Methodology of analysis

A database of policies from Europe, Japan, China, and USA was built, based on the data collected. It totals 3286 policies and contains the following sets of information about each of them: Title of policy, Description, Year, Implementation Status, Sectors affected, Decarbonization focus, Geographical coverage, Type of policy instruments.

In order to conduct an empirical assessment of the transformative potential of decarbonization policies, the transformative mechanisms proposed above are operationalized, as described in Table 1, and the policies compiled are examined to uncover eventual evidence of their presence. The respective variables were added to the database.

Table 1 – Transformative mechanisms - Operationalization

Mechanism	Criteria
Experimentation	Policies refer to any form of experimental activity, from test and demonstration of technologies to various types of social experiments.
Multi-actor Type of actors	Policies target /involve and/or refer to the creation of partnerships or other modes of cooperation between different types of actors. An additional variable is created to distinguish between policies targeting the “traditional” type of actors (industry, academia, government) from those also engaging “new” types of actors (civil society)
Multisector	Policies target / involve more than one sector of activity
Multiscale	Policies encompass more than one spatial scale: supra-national, national, sub-national (different possible levels)
Reflexivity	Policies refer to the monitoring and assessment of the progress towards goals; and/or explicitly refer to the incorporation of learning from such assessment
Instrument mix	Policies use more than one type of policy instrument.

The incidence and distribution by region and sector of policies displaying individual mechanisms and/or their combinations is assessed. Subsequently, a qualitative analysis looks in greater depth at a set of policies displaying combinations of mechanisms, to better understand the forms assumed by these mechanisms as well as the nature of the policies displaying them.

3. Results

3.1 General characterization of the decarbonization policies

This section provides a general characterization of the 3286 decarbonization policies that form the database. The analysis considers the breakdown, for each region, of policies in terms of the target sectors and the types of policy instrument used. These are aspects that will be addressed later in the analysis of transformative mechanisms.

Starting with the target sectors (Table 2), the results reveal that energy is the sector most targeted by decarbonization policies, and its relevance is particularly pronounced in the USA and China. Compared to other regions, Europe has targeted its policies more towards transport, waste and agriculture, forestry and land use (AFOLU). Japan stands out in cross-sectorial (transversal) policies.

Table 2 – Breakdown of decarbonization policies by target sector and region

Target sector	All regions		Europe		USA		China		Japan	
	N	%	N	%	N	%	N	%	N	%
Energy	1769	53.8	1057	46.1	397	70.6	215	77.1	100	65.4
Transport	725	22.1	590	25.7	64	11.4	46	16.5	25	16.3
Buildings	704	21.4	411	17.9	196	34.9	66	23.7	31	20.3
Industry	397	12.1	275	12.0	77	13.7	28	10.0	17	11.1
Waste	197	6.0	187	8.2	6	1.1	2	0.7	2	1.3
Cross-sectorial (Transversal)	237	7.2	132	5.8	63	11.2	22	7.9	20	13.1
Mineral resources	50	1.5	2	0.1	30	5.3	9	3.2	9	5.9
AFOLU*	451	13.7	439	19.2	7	1.2	4	1.4	1	0.7
Total**	3286	100	2292	100%	562	100	279	100	153	100

*Agriculture, Forestry and Land Use; **It does not correspond to the sum of the lines as some policies are being targeted at more than one sector

Regarding the policy instruments used, the instruments listed in the source databases were organized in four types. Economic (market-based) instruments use market mechanisms to achieve environmental objectives, and include subsidies, taxes, charges and emissions trading and other tradeable permit systems. Regulation (command-and-control) instruments include laws and regulations, mandatory standards, bans, and mandatory product labeling. Soft instruments attempt to influence people's behavior by giving new information or changing the information environment in which they make decisions or by using behavioral public policy methods such as nudges. They include information, education campaigns, and voluntary agreements. Planning policy instruments help to define and achieve policy goals, and include zoning, land-use planning and transportation planning.

The most commonly used instruments are the “traditional” market and regulation based instruments (Table 3). In relative terms, it can be seen that Europe tends to favor economic instruments, while the other countries favor regulatory instruments. It should also be noted that planning has a greater weight in China than in the other regions, particularly the USA.

It is common that policies involve a mix of instruments. In this paper, we consider instrument mix at the level of instrument types. The results show that 72,3% of the policies are making use of only one type of instrument. Japan has the highest weight of policies that use a mix of instrument types.

Table 3 – Breakdown of decarbonization policies by instrument type and region

Instrument type	All regions		Europe		USA		China		Japan	
	N	%	N	%	N	%	N	%	N	%
Economic	1592	38.3	1193	41.9	242	31.8	84	25.1	73	33.8
Regulatory	1517	36.5	908	31.9	352	46.2	167	49.9	90	41.7
Soft	609	14.6	443	15.6	112	14.7	27	8.1	27	12.5
Planning	443	10.6	304	10.7	56	7.3	57	17.0	26	12.0
More than one instrument type	869	27.7	563	24.6	172	30.6	78	28.0	56	36.6

3.2 Policies with transformative potential

Presence of transformative mechanisms has been proposed as an indication of policies transformative potential (TP). Transformative mechanisms were found in only a minority of decarbonization policies (Table 4). In fact, only 15.5% of the mitigation policies include at least one of the studied mechanisms. Combinations of mechanisms, which may configure with greater transformative potential in policies, were even less frequent (less than 5%) and no single policy integrated all the mechanisms. Diversity of actors and experimentation were the most common transformative mechanisms, while reflexivity was the less frequent.

Table 4 – Policies with transformative mechanisms

Mechanism	Number of policies	% total
Reflexivity	89	2.7
Experimental	174	5.3
Multi-actor (all)	214	6.5
Of which involve new actors	138	2.3
Of which only involve traditional actors	76	4.2
Multi-sectoral	109	3.3
Multi-scale	108	3.3
Policies with at least one mechanism*	510	15.5
Policies with two mechanisms*	118	3.6
Policies with three or more mechanisms*	33	1.0

*using multi-actor (all)

Policies with more than one mechanism are organized in a variety of forms, i.e., they show different combinations of mechanisms. Experimentation & diversity of actors, and diversity of actors & variety of sectors & multi-scale coordination were the most frequently seen in combination (Table 5). Moreover, the most frequent combination of three mechanisms involves experimentation, diversity of actors and diversity of sectors.

Table 5 – Combination of mechanisms (number of policies)

	Reflexivity	Experimental	Multi-actor	Multi-sectoral	Multi-scale
Reflexivity	-	12	20	24	6
Experimental		-	37	20	13
Multi-actor			-	37	38
Multi-sectoral				-	13
Multi-scale					-

Regional differences in policies with transformative potential (TP)

Almost half of the policies with transformative mechanisms have been implemented in Europe, but in this region only about 10% of decarbonization policies have transformative potential (Table 6), the lower value among the regions analyzed. The weight of policies with transformative potential is clearly higher in the USA. In Europe (Table 7), there is a wide variation in the importance of countries in the share of policies with transformative potential, as well as in the weight they have in the total of decarbonization policies. In the latter, the Netherlands, Slovenia and Croatia stand out.

Table 6 – Policies with transformative mechanism, by region

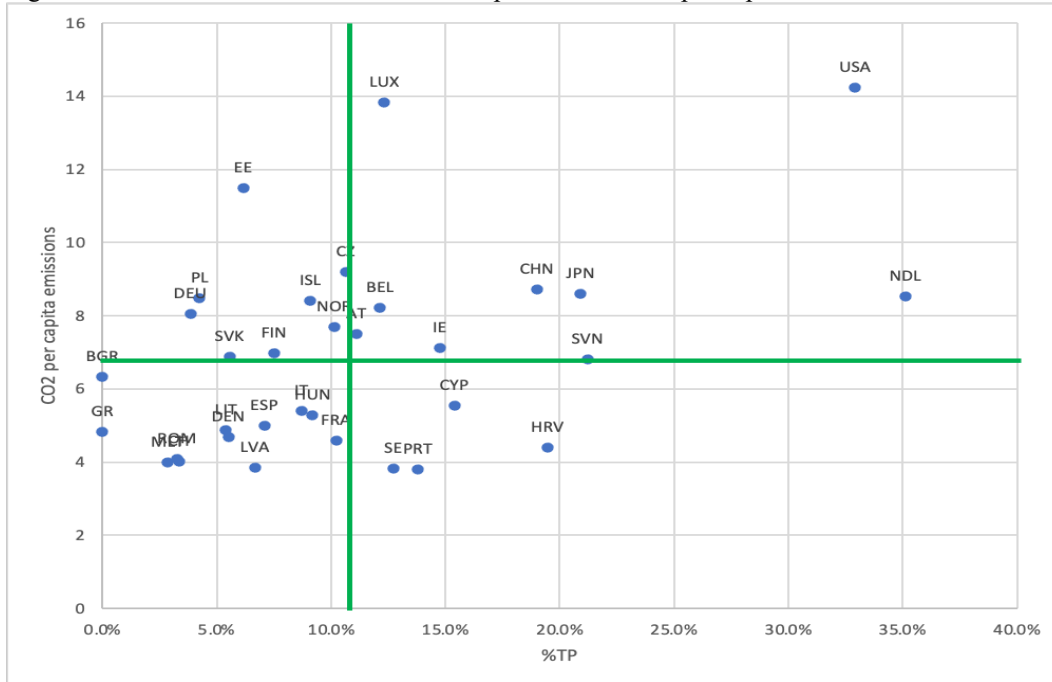
Region/Country	Share of TP in decarbonization policies in the country/region (%)	Share of country/region in all TP (%)
China	19.0	10.4
Europe	10.5	47.1
Japan	20.9	6.3
USA	32.9	36.3
Total	15.5	100.0

Table 7 – Policies with transformative mechanism, in European countries

Country	Share of TP in decarbonization policies in the country/region (%)	Share of country/region in all TP (%)
Austria	11.1	0.6
Belgium	12.1	5.1
Bulgaria	0.0	0.0
Croatia	19.5	4.3
Cyprus	15.4	0.4
Czechia	10.6	1.0
Denmark	5.5	1.2
Estonia	6.2	0.8
Finland	7.5	1.2
France	10.2	3.7
Germany	3.8	0.6
Greece	0.0	0.0
Hungary	9.2	1.6
Iceland	9.1	1.0
Ireland	14.8	1.8
Italy	8.7	0.8
Latvia	6.7	1.2
Lithuania	5.4	1.2
Luxembourg	12.3	1.8
Malta	2.9	0.4
Netherlands	35.1	6.5
Norway	10.1	1.4
Poland	4.3	0.4
Portugal	13.8	0.8
Romania	3.3	0.6
Spain	7.1	1.6
Slovakia	5.6	0.5
Slovenia	21.2	5.5
Sweden	12.7	1.4
Switzerland	3.3	0.2

Figure 1 suggests that the USA, China and Japan may be under more pressure to adopt more transformative policies, given the higher level of CO2 per capita emissions. This is also the case of some of the European countries with a higher share of TPs, such as the Netherlands and Slovenia.

Figure 1 – Share of TP in all decarbonization policies and CO₂ per capita emissions*



*2021 data retrieved from IEA-EDGAR CO₂, a component of the EDGAR (Emissions Database for Global Atmospheric Research) Community GHG database version 7.0 (2022)

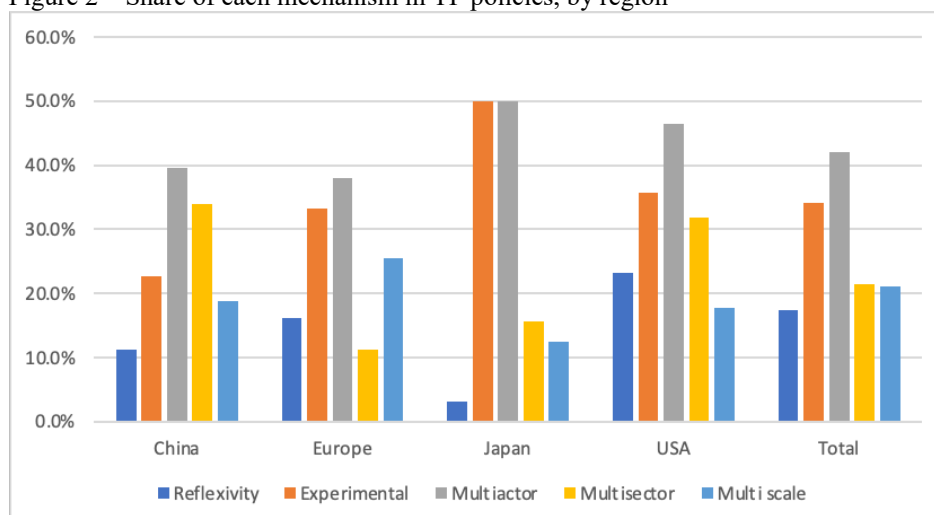
A closer look at the regional distribution of the presence of each transformative mechanism under analysis in the policies (Table 8), reveals that the USA and Europe share the leadership: the USA dominates in the presence of reflexivity and variety of sectors and Europe in the remaining mechanisms.

Table 8 - Share of regions in each TP mechanisms (%)

	Reflexivity	Experimental	Multi-actor	Multi-sector	Multi-scale
China	6.7	6.9	9.8	16.5	9.3
Europe	43.8	46.0	42.5	24.8	56.5
Japan	1.1	9.2	7.5	4.6	3.7
USA	48.3	37.9	40.2	54.1	30.6
Total	100.0	100.0	100.0	100.0	100.0

Complementarily, Figure 2 reveals the mix of mechanisms in each region. There is some diversity across regions, highlighting: i) the low weight of reflexivity in Japan, where experimentation and the variety of actors are very important; ii) the weight of multi-scalarity in Europe; and ii) the weight of the variety of actors in China and the USA.

Figure 2 – Share of each mechanism in TP policies, by region*



* Since policies can combine several mechanisms, the sum may be greater than 100%

Sectoral differences in policies with transformative potential

Transversal policies are potentially more transformative (Table 9), since a higher proportion of them has at least one transformative mechanism. The energy sector, particularly alone, and to a lesser extent in association with industry and transport, was also one of the most likely to display transformative policies. Moreover, policies that combine buildings and transport tend to be transformative.

Table 9 - Sectoral distribution of TP

	All policies	Policies with TP mechanisms	% with TP
One sector	2313	244	10.5
Energy	677	144	21.3
Transport	486	40	8.2
Buildings	36	4	11.1
Industry	144	20	13.9
AFOLU*	383	28	7.3
Waste	152	5	3.3
Mineral resources	15	3	20.0
Cross-sectorial (Transversal)	237	94	39.7
Sector mixes			
Energy & Buildings	647	94	14.5
Energy & Transport	217	38	17.5
Energy & Industry	212	42	19.8
Energy & AFOLU*	52	5	9.6
Buildings & Transport	24	7	29.2

*Agriculture, Forestry and Land Use

3.3 Qualitative analysis of a set of policies

A qualitative, in-depth content analysis enabled us to study in more detail the policies displaying more extensive combinations of mechanisms, to better understand their mode of organization. The selection of policies for this analysis sought to cover: i) all regions and, in the case of Europe, countries that stand out in terms of TP; ii) the most frequent target sectors (and their combinations); iii) different decarbonization focuses; iv) different mixes of instruments. The variety of combinations in these different dimensions is shown in the information contained in Table 10. Table 11 displays the results of the content analysis, showing how the different mechanisms are organized in each of the selected policies.

Table 10 – General characterization of policies selected

Policy	Country	Sectors	Decarbonization Focus	Number of TP mechanisms	Instrument Mix
Collective self-consumption	Belgium	Energy	Renewable energy Other	3	Voluntary/negotiated agreement
Renolab: Renovation laboratory – RBC	Belgium	Energy Buildings	Resource efficiency, circular economy	2	Economic, Information, Research
Top 1000 Industrial Energy Conservation Programme	China	Industry	Energy Efficiency	4	Voluntary/negotiated agreement
China Urban Transport Development Strategy and Partnership Demonstration Projects	China	Transport	Transport efficiency	4	Economic, Regulatory
Soft energy efficiency measures in the period 2021-2030	Czechia	Cross-sectorial (Transversal)	Energy Efficiency Consumption Reduction	2	Education; Information
Territorial climate air energy plans	France	Cross-sectorial (Transversal)	Emission and Climate mitigation Renewable energy Demand Management	4	Planning
Promotion of integrated and intelligent transport systems and development of alternative fuels infrastructure at local and regional level	Croatia	Transport	Transport efficiency Local development Renewable energy	2	Economic, Information
Promoting a just transition	Hungary	Energy Industry	Environmental/Ecological/Energy Transition Economic development	2	Economic
Warmth and Wellbeing Pilot	Ireland	Energy Buildings	Renewable energy Public Health, wellbeing	3	Economic
Promotion for Development and Dissemination of PV systems	Japan	Energy	Renewable energy Technology R&D and innovation	2	Economic
Government wide Programme for a Circular Economy	The Netherlands	Cross-sectorial (Transversal)	Resource efficiency, circular economy	2	n.a.
Regional industrial cluster approach	The Netherlands	Industry	Emission and Climate mitigation	3	n.a.
Fossil Free Sweden	Sweden	Energy Transport Industry	Fuel Shift	3	Information
Education, training, awareness raising, information and promotion	Slovenia	Energy Transport Waste	Environmental/Ecological/Energy Transition	2	Economic, Education; Information

Funding for solar deployment in underserved communities	USA	Energy	Renewable energy Energy access	3	Economic
WINDEXchange	USA	Energy	Technology R&D and innovation Renewable energy	3	Education; Information,
Climate Showcase Communities Grant Program	USA	Energy Buildings	Renewable energy Energy Efficiency	3	Economic, Regulatory, Education; Information

Table 11 – Content analysis of policies selected focusing on the transformative mechanisms they include

Policy	Reflexivity	Experimentation	Multi-actor	Multisector	Multiscale
Collective self-consumption	“On the basis of lessons learned from pilot projects the government will support energy community development projects”	To “study the modification of the regional operating rules of the electricity”, the government promotes prioritizes “pilot projects” “with the aim of identifying the most favorable conditions and the simplest means for the development of collective self-consumption”	Community development projects are based on “voluntary grouping of residents located downstream from a neighborhood terminal for collective management of energy consumption and production”. “Support will also be granted to cooperatives for the deployment of energy production facilities whose share will be accessible to anyone wishing to participate in a collective project.”		
Renolab: Renovation laboratory – RBC		The policy support and enhances “quality renovation operations by being part of a desire to demonstrate the feasibility of the sustainable and circular renovation of buildings in Brussels and to encourage the reproduction of these examples.”	The policy “also aims to make sustainable renovation more attractive and to contribute to the emergence of new tools that fully support the renovation strategy, innovative financing, grouped renovation by initiatives that try to reduce fuel poverty by involving the poor in pilot projects; tools based on the real motivations of households: comfort at home, preservation of the property's heritage value, health, etc.”		

Top 1000 Industrial Energy Conservation Programme	“Clear targets for energy conservation should be established in the Plan. Energy conservation measures should be provided. Annual implementation plan should be involved. The Plan must be reviewed by provincial DRC or ETC.”		“Joins five central governmental agencies and provincial governments” [...] “Sector associations will play key roles in the creation of indicator and evaluation system. They will also play important roles in information collection and disclosure, training, and others.”	The policy includes all sectors to which energy conservation needs apply	“Beyond the five central governmental agencies, provincial governments will work on data collection, monitoring and guiding of enterprises, etc.”. “Governments at different levels should provide enterprise with economic incentives”
China Urban Transport Development Strategy and Partnership Demonstration Projects		“The programme includes urban transport policy development, capacity building and demonstration with a goal to change the current approach to urban transportation, land use, and investment policy design in order to promote sustainability and decrease pollution”	The “outputs will include training programs, conference presentations and perhaps other dissemination activities such as videos and audiovisual aids that provide guidance on sustainable transport issues to local decisionmakers, planners and the public nationwide.”	The policy includes sectors related to transportation, land use (including city planning services), and energy.	“The policy is a collaborative effort between the Ministry of Finance, NDRC, the World Bank, and the Global Environment Facility (GEF)”. Involves “comprehensive strategy to guide different elements of China governing structure on issues related to urban transport.”
Soft energy efficiency measures in the period 2021-2030			“It is a crosscutting programme and the target sectors are the state administration and local governments, private sector, households and NGO’s.”		Involves central and local governments.
Territorial climate air energy plans	The policy “includes a diagnosis, a territorial strategy, an action plan and a monitoring and evaluation system.”		Constitutes a framework of territorial commitment. It is intended to mobilize all economic, social and environmental players, under the impetus and coordination of a leading community.	The policy considers planning process, both strategic and operational, which concerns all sectors of activity.	The territorial plan is “supported by the inter-municipalities of more than 20,000 inhabitants and concerns the entire territory of the community”. “The

			The action program describes the actions to be implemented by the community and the actors of the territory.		objectives and priorities must be articulated explicitly with the existing regional plan.”
Promotion of integrated and intelligent transport systems and development of alternative fuels infrastructure at local and regional level	“It is necessary to continuously prepare and implement Sustainable Mobility Plans in cities, as well as strategic plans that build on the existing planning practices.”		It is necessary to “take into account integration, participation and evaluation principles to meet the citizens' mobility needs now and in the future, and ensure better quality of life in cities and their surroundings”.		
Promoting a just transition	“In order to achieve a ‘Just Transition’, the plans aims to provide an opportunity to monitor labour market developments with energy transitions and to reverse possible adverse trends”		Territorial Just Transition Plans are created for regions where the transition to a clean energy economy would endanger the jobs in fossil fuel intensive sectors. The policy “includes creating a more diversified economy, more stable, long term, more sustainable jobs, reduced vulnerability of consumers; reducing emissions of air pollutants; improving water management; restoration of mining areas; preparing the automotive supply chain for decarbonization.		
Warmth and Wellbeing Pilot	Following a successful study with over 1,300 homes upgraded the pilot was closed and new applications will be integrated into the Warmer Homes Scheme	The pilot was launched in Dublin. If pilot is deemed successful, based on findings from research being carried out in parallel by London School of Hygiene and Tropical Medicine, the	Initiative joins several government departments and agencies, and a research organization; it targets vulnerable people “in energy poverty that are living with chronic respiratory condition” and aims to provide “providing		

		scheme may be rolled out nationwide in the future.	extensive, deeper energy efficiency [home] upgrades”, testing the health benefits associated		
Promotion for Development and Dissemination of PV systems		International Joint Demonstrative Research of PV systems. PV Field Test Program for Industrial and Other Applications. Support for introduction of PV systems by innovative enterprises and local government, to encourage others to follow the example.	Introduction and promotion of PV systems for residences - Support for introduction of PV systems by innovative enterprises and local government. Support for NGOs activities to promote grassroots introduction of PV systems.		
Government wide Programme for a Circular Economy			“Sets out what we need to do in order to utilise raw materials, products, and services in more efficient and smarter ways. In this transition, many parties participate: companies, governments, knowledge institutes, NGOs and many more.	The government has selected 5 economic sectors and value chains that will be the first to switch to a circular economy.	
Regional industrial cluster approach	Include learning and development of synergies with other programmes, e.g. “regional transition programmes, joint permit and/or subsidy scheme approaches”	Five regional industrial clusters as front runners. The integrated approach aims at greenhouse gas reduction and sustainable use of resources and include aspects such as joint learning, coordination for infrastructural aspects (grids for electricity, hydrogen, heat, etc.).		Integrated approach through developing programmes for 5 specific regional industrial clusters (and a 6th cluster with participating other industries) including de 12 largest emitting companies.	

Fossil Free Sweden	Following assessment, the government has extended the initiative to 2024. It will support the business community in the recovery during and after the corona crisis. It also receives expanded assignments locally, regionally and internationally.		Strengthen the dialogue between the state and the business sector, municipalities and civil society		Interaction between central government and municipality levels
Education, training, awareness raising, information and promotion			Policy involves: trainings for the transition to a low carbon society for different target groups; integration of climate change related contents in curriculum at all levels of education process; provision of training programmes and information, awareness and promotion campaigns for different areas.	The policy includes all sectors concerned with energy conservation and waste prevention.	
Funding for solar deployment in underserved communities	Following assessment, decision to update and expand: “helped hundreds of local governments make it easier and more affordable to go solar and aims to help another 500 communities over the next five years”		Assistance for underserved communities: connects different actors to technical experts at DOE’s National Laboratories to develop innovative solutions to regional challenges associated with solar energy adoption; encourage more equitable solar deployment		Interaction between federal government and local community levels
WINDEXchange	Provides information to inform policy decisions and incentive conversations as well as links and summaries of	Designs a network “to educate, engage, and enable critical stakeholders to make informed decisions about how wind energy can	“Network of state wind working groups, state energy officials, DOE and national lab representatives and professional and institutional partners.		help states and regions build capacity to support and accelerate wind energy deployment

	activities at the local, state, and regional level	contribute to the U.S. electricity supply”	“Offer awards to: public-owned utilities and cooperatives for their leadership in promoting wind energy development; the first utility-scale wind projects in a state; and outstanding partners and advocates”		
Climate Showcase Communities Grant Program		Grantees actions and accomplishments are showcased through web resources and peer exchanges. Fifty Climate Showcase Communities across the US are leading projects in various areas.	Helps communities create replicable models of sustainable community action that generate cost-effective and persistent greenhouse gas reductions while improving the environmental, economic, public health, or social conditions in a community.	Projects involve and/or combine energy production, residential and commercial energy efficiency, waste management, transportation and land use.	

The analysis of the transformative mechanisms permitted us to reach some conclusions about the forms they assume and the ways they may contribute to induce transformative effects in policies.

Multi-actor. The involvement of a variety of actors was the most frequent mechanism in the policies analysed. Although in some cases the focus was on the “traditional” actors (industry/academia), an already substantial number included non-traditional actors, from the civil society. These policies ranged from the involvement of local communities to achieve sustainability goals, or the encouragement of collaborative activities at various levels, to policies aiming at increasing the awareness and/or training of these types of actors. Frequently these activities were part of experimentation processes.

Multi-sector. Multi-sector was usually combined with multi-actor, as the different actors involved might come from different sectors of economic activity or society domains. Policies including this mechanism often entailed establishment of connections / creation of interactions between sectors usually not related, aiming at a common goal (ex: energy savings; efficient use of resources / circular economy).

Experimentation. Experimentation is also one of the most frequent mechanisms. Policies including it could be divided into two types. On one hand there were policies focused on technology development which included different modes of test and demonstration as a route towards technology diffusion. While some of these appeared to have as targets mostly companies that might further develop and commercialize the technology (even if input from other actors might be considered), others had a broader approach and encompassed a wider range of contributions, namely from the user side. On the other hand, there were policies that included different types of societal experimentation, aiming at changing social practices (e.g., in terms of energy use, transportation, urban living conditions) involving a wider variety of actors, and sometimes expected to be driven or coordinated by local communities (including an important role for municipalities) or other social groups. Finally, there were also policies that aimed at changes in energy use practices only at industry level, namely using the pilot programmes as showcases, to show the way and encourage other firms to follow the example.

Multi-scale. Policies encompassing and involving coordination between different spatial levels, were mostly of two types. They could be formulated at a higher level (usually national) and then implemented at other levels (regional and/or local), the higher level usually assuming coordination. But they could also originate at lower levels and act as pilot actions that were a learning setting that based dissemination to higher levels. Regarding the former, it is worth mentioning that the supra-national level as coordinator of activities being conducted at national (and sometimes regional level) was also present in some policies. This was namely the case of Europe, in which a substantial number of policies were based on EU level policy directions.

Reflexivity. A number of policies mentioned monitoring and assessment and their use to inform subsequent decisions, namely extension or reformulation of the policy, or the launch of subsequent policies. However, while in some cases the presence of learning effects was suggested, in general the type of information available did not enable us to assess the actual level of reflection about the policy.

Several of the policies analyzed make use of a mix of different types of instruments. When a combination of instruments is absent there is either the use of economic stimuli (for instance to mitigate negative effects of transition or to support disadvantaged communities), or the use of various soft instruments, associated to changing people’s behavior. Research has shown that these instruments favor the acceptance of change and increase the effectiveness of policies (Geels et al, 2019).

4. Conclusions

This paper proposed literature derived mechanisms that are expected to introduce transformative effects in policies and investigated their presence in a broad set of decarbonization policies.

The analysis showed that policies including transformative mechanisms – thus having a transformative potential – are still a minority in the four world regions analyzed. However, there were some regional differences in the incidence of policies displaying them, as well as in the relevance of different mechanisms.

The highest incidence of policies with transformative potential was in the USA, followed by China. While Europe was the region with the greater number of decarbonization policies, it was also the one with a

lower incidence of policies with transformative potential. Besides eventual classification problems, due to lack of information, it is possible to suggest two possible explanations for this result. One is the urgency to tackle decarbonization problems, which may be higher in the USA and China given their higher level of CO₂ emissions. On the other hand, these countries started formulating decarbonization policies relatively later than Europe, which may mean that they have a higher proportion of more recent policies, which are more likely to already incorporate the new policy rationales.

Concerning the sectoral incidence of policies with transformative potential, the analysis showed that it was higher in the policies that had a transversal focus. This result was not unexpected as these policies have a greater capacity to bring together different sectors and actors aiming at a common goal. As expected, policies targeting the energy sector also included more frequently transformative mechanisms, the higher incidence being when alone or combined the industrial sector. This may be related to the centrality of energy in decarbonization processes and the growing awareness of the need to decarbonize industrial activities. More unexpected was the high incidence in policies targeting a combination of buildings and transport, which may be associated with the expansion of the electric charging infrastructure of vehicles, or of policies aiming at changes in the organization of cities towards sustainability.

Finally, in what concerns the relative relevance of different transformative mechanisms, there are two relevant findings. One is the importance of the involvement of a variety of actors and, in particular, the growing policy focus on civil society actors and local communities (on their own or as part of multi-level processes). The other is the relevance of experimentation, which is increasingly moving from supporting technology diffusion through demonstration activities, towards a broader focus on changing social practices, through a diversity of social experiments, bringing together and engaging different actors. This also introduces a cautionary note to approaches that aim to tackle decarbonization mainly by stimulating embryonic innovations as they are still too far from involving experimentation and engaging relevant actors.

One important contribution of this research was to go beyond case studies and assess the incidence of transformative mechanisms in a wide range of policies. However, this more encompassing approach also was found to have some limitations. In fact, as some policy descriptions (albeit still a minority) were insufficient to reach a conclusion about an eventual presence of the transformative mechanisms defined, the incidence of policies with transformative potential reported may be undervalued.

Overall, the results suggest that there are already, across different world regions, efforts towards the inclusion of different types of transformative mechanisms in policies, which are promising to accelerate decarbonization. The definition of these mechanisms and their analysis is a first step towards assessing decarbonization policies' ability to produce co-benefits for the economy, but further research is needed in order to go into greater depth into the nature and effects of these policies.

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