for measuring circularity (Whalen and Whalen, 2020). Based on the above, public policy frameworks could enable some broad conditions for circular economy, including:

1. The more intensive use of an existing (or reduced) stock of resources.

2. The development of secondary markets to aid circular flows.

3. Mechanisms/measures to prevent or mitigate unintended consequences or circular economy rebound effects.

3. Framework of economic signals to incentivize further decarbonization through the circular economy

Following from the above, circular economy approaches could be aided by the development of a cohesive public policy framework of incentives to:

- enhance decarbonization (alongside existing measures),
- optimize material flow,
- minimize waste across supply chains.

The types of existing policy signals can be broadly categorized into:

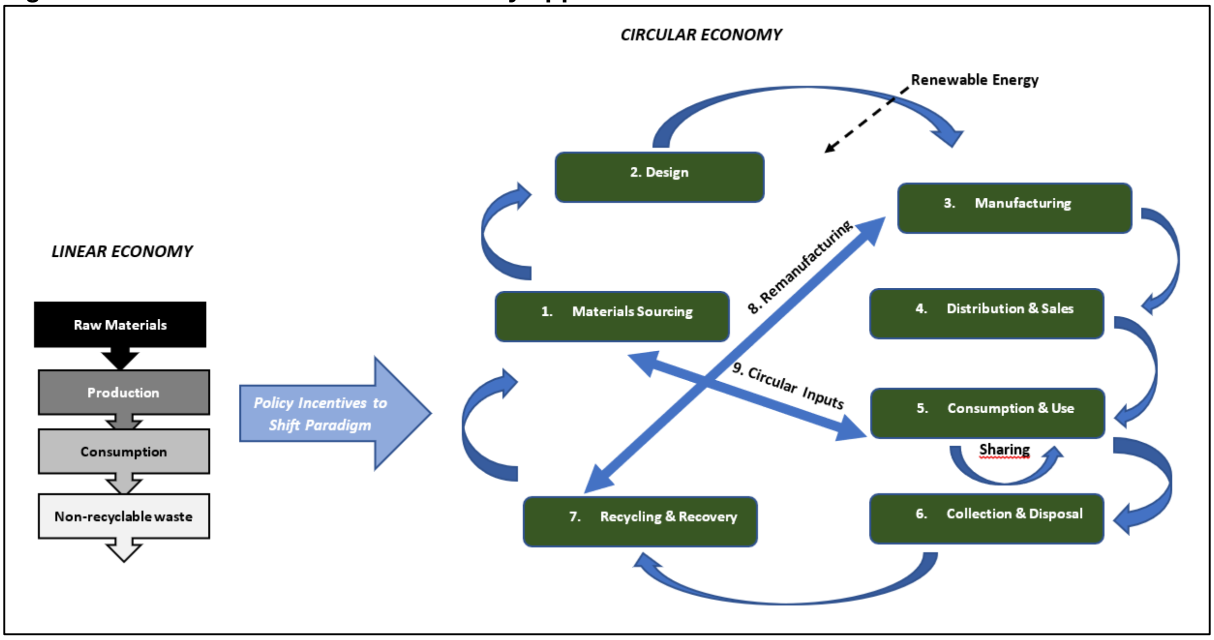
- incentive mechanisms that promote market-based outcomes (such as carbon prices, emissions trading systems, and tradable permits or standards),
- regulatory incentives (for example industry-specific regulations, technology mandates, or non-tradable performance standards).

Although there is an existing set of policy instruments aimed at incentivizing decarbonization across countries, in practice, no major market economy has achieved a cohesive set of policy measures to incentivize 'full' decarbonization (Day and Sturge, 2019). Most countries have a mix of policy signals (including taxes, subsidies, standards, and regulations) which give rise to uneven incentives to reduce carbon (and other GHG) emissions across their economies. An effective framework of policy signals would ideally reflect some key consistent features (Stahel, 2013) such as:

- applying to emissions across the supply chain,
- correctly pricing in externalities,
- incentivizing accurate and cost-effective emissions measurement, verification, and reporting.

Policies to drive circular economy transitions at the macro level are also likely to result in structural shifts involving the decline of certain sectors and the rise of others, with potential reallocations of capital and labour (OECD, 2017). A public policy framework would therefore need to include mechanisms which mitigate any negative effects.

Figure 5: Linear versus circular economy approaches



Source: Kalmykova et al. (2018); Govt. of the Netherlands (2017)

Table 4 synthesises the circular economy objectives and metrics that have been used by companies and organizations, and attempts to map them onto existing policy measures that create economic incentives to induce shifts in the current linear paradigm (also see Figure 5). Column 1 of the table represents the key features of circular economy:

- efficiency,
- substitution,
- durability,
- ecodesign,
- increased intensity of use (through consumer choice and a focus on services),
- recyclability,
- industrial symbiosis.

Column 2 summarizes the relevant objective. Column 3 details metrics commonly used at the organization level. Column 4 represents complementary instruments of decarbonization. Column 5 illustrates some country examples.

3.1 Market-based incentives

Amongst market-based incentives in Table 4, *carbon prices* penalize the negative externalities according to the 'polluter pays' principle; energy producers and consumers internalize the costs of carbon-intensive fuels and activities, and the use of low- and zero-carbon energy sources and activities is encouraged. They also help to equate the marginal abatement cost of all sources of emissions (Blazquez and Dale, 2020). Economy-wide carbon prices have proved difficult to implement thus far and what exists in most countries is a 'patchwork mix' of taxes (such as VAT and excise duties) and subsidies (for example feed-in tariffs and agricultural subsidies). Day and Sturge (2019) distil these taxes and subsidies to compute 'effective carbon prices'[54] for different fuels and economic sectors/activities in the UK and argue that they are too low to incentivize emissions reduction, particularly in sectors such as residential gas, agriculture, and aviation.[55] Explicit carbon prices are imposed through cap-and-trade schemes, in which the total allowable emissions in a country or region are set in advance; permits to emit are created to match these and are then allocated or auctioned to companies, which then trade permits, creating a market to achieve emissions reduction at least-cost (Bowen, 2012). The effectiveness of cap-and-trade schemes can be constrained by the fact that the carbon price set by the scheme needs to be sufficiently high to encourage behavioural change, and the scheme itself should be wide enough in its scope and coverage to prevent carbon leakage[56] (Bowen, 2012). These constraints often mean that governments may intervene to re-set allocations or introduce secondary measures to mitigate leakages, potentially undermining the long-term credibility of the market.[57] In Table 4, carbon prices and carbon-related efficiency trading schemes are signals to incentivize *efficiency* and *substitution*; however, in contrast with a linear approach in which incentives (such as carbon allowances or credits) are provided to reduce emissions, in a circular model, mechanisms could be designed to minimize and then prevent emissions (Stahel, 2013).

Fiscal incentives offer an alternative set of market-based incentives to enable the optimization of existing stock. For instance, taxing negative externalities at the ends of the supply chain could make resources relatively costlier upstream; in theory, this might stimulate greater reuse and recycling of materials,[58] and stimulate circular approaches downstream (for example through recycling). However, this approach is not without tradeoffs, Day and Sturge (2019) argue, for instance, that any such changes should be accompanied by policy measures to improve efficiency and stimulate innovation. Similarly, it has been argued that lower VAT rates on labour-intensive services could incentivize repair and reuse, and reduce waste (Bock, 2017). Fiscal incentives could be applied in the context of decarbonization to incentivize *durability*, *ecodesign*, *increase the intensity of use*, and *recyclability*. The caveat to these measures is the assumption that consumers will respond to these in a rational or expected manner which, evidence suggests, is not always the case (this is discussed further in Section 4).

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[54] A measure of how much a firm or an individual is paid or rewarded per tonne of carbon (or CO_2e) saved when they make a choice that lowers emissions.

[55] For instance, because VAT on some of these sectors/activities was relatively low (Day and Sturge, 2019).

[56] Polluting companies may move to jurisdictions which lie outside the borders of the scheme. This reduces the effectiveness of unilateral or multilateral carbon pricing (Blazquez and Dale, 2020).

[57] This was the case with the initial launch of the EU Emissions Trading Scheme, which was later remedied to correct for leakages and distortions. Similarly, under India's PAT scheme, market participants who overachieve efficiency targets are issued certificates equivalent to 1 tonne of savings, which they can trade. Early rounds of the PAT yielded low market clearing prices, indicating a potential oversupply of certificates.

[58] In this aspect, the circular economy does not differ from the industrial economy and can benefit from efficient markets matching supply with demand for the service-life extension of goods – processes such as component repairs, remanufacturing and upgrading, and remarketing goods and components (Stahel, 2013).

Table 4: Mapping circular economy metrics from organizations onto existing government policy incentives – a framework

Component of circular economy (1)	Objective (2)	Organization-specific metrics (3)	Existing government policy incentives (4)	Select country examples (5)
Efficiency	Reducing the use of energy and materials in production and use phases.	▪ *Materials price variation.* ▪ *Material supply chain risks.* ▪ *Standard material recovery rates.* ▪ *Mass of material inflows defined as 'critical' or 'scarce' as % of the total mass of linear inflows.* ▪ *Value (revenue) a company generates per unit of linear inflow.* ▪ *Energy usage & CO_2 emissions; Water usage.*	▪ *Energy efficiency trading schemes.* ▪ *Performance-based standards.* ▪ *Carbon pricing.* ▪ *Cap-and-trade schemes.*	India's Perform–Achieve–Trade (PAT) scheme – a cap-and-trade certificates system – covers individual industry plants that cross a threshold of energy consumption. Specific energy consumption (SEC) reduction to be attained within a particular PAT cycle.
Substitution	Reducing the use of materials that are hazardous or difficult to recycle in products and production processes.	▪ *Renewables as % of energy consumption.* ▪ *Monitoring/reducing the mass of material inflows defined as 'critical' or 'scarce' as a percentage of the total mass of linear inflows.* ▪ *Monitoring material toxicity.* ▪ *Energy usage & CO_2 emissions, Water usage.*	▪ *Carbon pricing.* ▪ *Cap-and-trade schemes.* ▪ *Renewable purchase obligations.* ▪ *Renewable support schemes.*	EU Emissions Trading Scheme (ETS) – EU carbon markets saved cumulative emissions of about 1.2 billion tons CO_2 from 2008–16, or roughly 3.8% relative to total EU emissions – with the major impact in power generation (Bayer and Aklin, 2020).
Durability	Lengthening products' useful life.	▪ *Material potential and actual recovery (see above).*	▪ *Depreciation accounting.* ▪ *VAT rates.*	Sweden and Luxembourg apply lower VAT rates to the repair of certain goods in the economy to prolong their use.

Component of circular economy (1)	Objective (2)	Organization-specific metrics (3)	Existing government policy incentives (4)	Select country examples (5)
Ecodesign	Designing products that are easier to maintain, repair, upgrade, remanufacture, or recycle.	▪ *'Recovery potential' (can be improved through optimizing design).*	▪ *Performance Based Standards.* ▪ *VAT rates.*	EU Ecodesign Working Plan: 28 ecodesign regulations; 16 energy labelling delegated regulations in support of material efficiency requirements, such as availability of spare parts, ease of repair, and facilitating end-of-life treatment.
Increased intensity of use (including consumer choice and focus on services)	Increase the intensity of use of goods by encouraging wider and better consumer choice through renting, lending, or sharing services as an alternative to owning products, while safeguarding consumer interests.	▪ *Material potential and actual recovery (can be improved through adopting new business models – e.g., product-as-a-service or buyback/take-back scheme – or collaborating with value chain partners that drive circularity).* ▪ *Share of sustainable products in portfolio.* ▪ *Customer attitude towards green products.*	▪ *Product subsidies.* ▪ *VAT rates.* ▪ *Carbon labelling programmes.* ▪ *Depreciation accounting.*	EU 'Product Environmental Footprint' Methodology. USA, Peru, Taiwan, Italy, Costa Rica, France, South Korea, Thailand, and Japan are developing or have established 'carbon footprint labelling programmes' – although these are voluntary initiatives in most countries, offered to products and organizations. France's 2019 LOM (Mobility Orientation Law) contained a package of fiscal and regulatory measures to catalyse shared mobility and Mobility-as-a-Service in the automobile sector.

Component of circular economy (1)	Objective (2)	Organization-specific metrics (3)	Existing government policy incentives (4)	Select country examples (5)
Recyclability	Incentivizing separation, collection systems that minimize the costs of recycling and reuse. Creating markets for secondary raw materials (i.e., 'recyclates'). Incentivizing and supporting waste reduction and high-quality separation by consumers.	▪ *Minimizing the use of virgin feedstock.* ▪ *Avoiding unrecoverable waste.* ▪ *Altering linear flow.* ▪ *Recycling rates & recycling efficiencies.*	▪ *Recycling standards.* ▪ *Public procurement policies.* ▪ *Taxation of waste.* ▪ *VAT rates.* ▪ *Changes in depreciation accounting.* ▪ *Renewable support schemes.*	US Sustainable Materials Management Program Strategic Plan focuses on reducing life cycle environmental impacts of materials (EPA, 2015). China's objective of reusing 72 per cent of industrial solid waste (Mathews and Tan, 2016). China's government introduced VAT incentives for the circular use of materials, such as agricultural, industrial, and domestic waste. Sweden and Luxembourg apply lower VAT rates to the repair of certain goods in the economy to prolong their use.
Industrial Symbiosis	Facilitating the clustering of activities to prevent by-products from becoming wastes.	▪ *Material potential and actual recovery (can be improved through adopting new business models – e.g., product-as-a-service or buyback/take-back scheme – or collaborating with value chain partners that drive circularity).*	▪ *Carbon border adjustment mechanisms.* ▪ *R&D support.*	Kalundborg (Denmark): an oil refinery, a power station, a gypsum board facility, and a pharmaceutical company, share ground, surface & waste-water, steam, and fuel, and also exchange a variety of by-products that become feedstocks in other processes.

Source: Based on EC (2014); EMF (2012a; 2012b; 2020); WBSCD (2020); Enel (2018)

Market-based mechanisms currently being discussed around curbing leakages through embodied emissions (for example from energy installations and the supply chain), and also potentially incentivizing *industrial symbiosis* within circular systems (in other words, the sharing of resources between industries/sectors within an economy) include carbon border adjustments. Assuming the 'border' is a national one, at the basic level, these are mechanisms which adjust the costs of imports and exports in a manner that takes account of differences in carbon prices. These mechanisms have been debated from different perspectives: one views them as a way of avoiding trade distortions and increasing the effectiveness of domestic carbon price policies; while another views them as a protectionist measure with unfair consequences for developing nations (Blazquez and Dale, 2020). Concerns have been raised by developing countries that lack carbon pricing mechanisms over the impact on the competitiveness of their exports and solutions are needed to address this. Examples of some proposed solutions include recycling a portion of the revenues into a fund that mitigates negative impacts for developing countries, and full or partial policy coordination with third countries (Falcao, 2020).

3.2 Standards and regulations

Table 4 shows that the balance of existing policy incentives currently leans towards standards and regulations, although these come with trade-offs (discussed in Section 4).[59] Standards and regulations can be used in stimulating the transition to circular economy approaches in countries which do not have fully developed markets or market mechanisms. For example, Renewable Purchase Obligations, encouraging *substitution*, were responsible for the early uptake of renewable electricity in developed and developing countries. Non-tradable performance-based standards (as opposed to prescriptive standards) could be used to incentivize *efficiency* and *ecodesign* in a circular economy (for example with regards to energy installations) – the drawback being the high transaction costs of monitoring and compliance, which require close coordination between governments and industry (IEA, 2018b), in addition to well-developed institutions.

Changes in depreciation methods may incentivize *durability* and *recyclability*, as well as a shift towards a *services-based* model; they could also aid the development of second-hand markets for products, increasing their value and preventing them from being depreciated to zero (Bock, 2017).[60] Similarly, life-cycle carbon accounting in the supply chain – for instance, to take into account the decommissioning impact of unused equipment with no residual life, and the relocation of used equipment to a different utilization setting (for example second-life batteries) or geographical area – could incentivize the same three parameters. Public procurement could be an additional way to incentivize *efficiency* and *recyclability*; government procurement of products with low embodied carbon could then also stimulate demand (for example, applying similar standards to areas of regulation such as building codes could incentivize contractors to build to low-carbon specifications (IEA, 2018b)).[61] Standards that take into account their environmental impact could also be specified for energy installations – for instance, Parrique et al. (2019) discuss the 'energy return on investment' (the ratio of the quantity of energy obtained from a resource to the quantity of energy that must be spent to extract it) as a possible metric. This is a measure of net energy output, differentiating between the costs and surplus of energy; a declining return means that an increasing portion of energy output must be allocated to obtaining

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[59] An obvious disadvantage of non-market approaches is the information asymmetry faced by policymakers while enforcing these standards or regulations.

[60] This also brings up the issue of when in the life cycle a reusable resource should be taxed. One proposal has been to impose VAT on material resources only once, and then on net margins (instead of gross margins) from its recirculation in the economy (Bock, 2017).

[61] For instance, the Netherlands instituted embodied carbon reporting in 2013. It requires whole-building LCA at the buildings permitting stage, facilitated by a national Environmental Product Declaration database and a standardized LCA method. A mandatory cap was adopted in 2018 for the 'environmental profile' of new homes and offices. The environmental profile translates multiple criteria, including embodied carbon, into a single measurable metric (IEA, 2018b).

energy, which means an increase in resource use and impacts. Several countries are developing, or have established, 'carbon footprint labelling programmes'.[62] These are voluntary initiatives in most countries and they are offered for products and organizations; net-zero carbon policies could see countries scaling up these programmes into tradeable carbon standards (Day and Sturge, 2019). 'Green' labelling and certification programmes are gaining prominence within policy frameworks; the ISO-certified voluntary 'Ecolabel' programme in the EU, and India's 'star labelling' programme for consumer appliances are examples of such schemes.

4. Barriers to implementation

From the discussion above, it is evident that circular economy strategies complement decarbonization policy, and can potentially be integrated into the latter by exploiting the synergies between metrics that are typically used to measure circularity within specific organizational contexts, and the wider set of instruments of decarbonization policy. However, in practical terms there are barriers to their implementation. We outline three main barriers below.

4.1 Government regulations

As discussed earlier in the paper, one condition for achieving circular economy is if global demand for both the volume and composition of products can be stabilized.

In contrast, prevailing government regulation is still dominantly oriented towards the linear model of economic operation and hence linear decarbonization. Most regulation aims at enabling decarbonization through least-cost methods, but without fully internalizing the costs of externalities. This means that technologies and their underlying supply chains are optimized for a linear model – that is, to minimize the cost in a predominantly 'take-make-waste' system. This has several implications.

First, in a linear paradigm, the different components of the circular economy (outlined in Column 1 of Table 4 above) tend to push in opposite directions and generate the need for undesirable trade-offs. For instance, *efficiency* trades-off with *durability* and *ecodesign*, as efficiency is a cost-driven parameter.[63] Similarly, *consumer choice* trades-off with *recyclability* – as the limits of recyclability in a linear paradigm can act as a constraint to consumer choice (for example, recycling in some hard-to-abate sectors can lead to negligible benefits or to unintended consequences such as higher energy use, as discussed in Section 2.3). The relatively higher costs of labour vis-à-vis the lower cost of bulk materials in some developed countries has led to a situation in which excess materials are used to allow a saving in labour costs (Allwood, 2014).

Second, the implementation of market-based incentives to stimulate economic incentives in one area often leads to distorted incentives and unintended adverse impacts in other areas. For example, measures imposed at the end of the value chain (such as taxes) with the intended effect of reducing wastage or emissions or other negative externalities, could distort an agent's economic incentives, impeding the creation of a closed loop. This is seen from evidence that imposing high taxes on the disposal of waste has, instead of minimizing waste, led to higher levels of illegal landfill in many countries (Matheson, 2019).[64] As discussed earlier, in a linear model, incentives to stimulate energy efficiency could create a rebound effect, leading to an increase of consumption of the same product or service, or to a reallocation of 'freed' resources to other types of carbon-emitting activity. Similar issues affect the application of regulations to the circular economy: for instance, secondary markets could be impeded by regulations that can increase the transaction costs for market participants, or which could

[62] For instance, USA, Peru, Taiwan, Italy, Costa Rica, France, South Korea, Thailand, and Japan.

[63] For example, what is efficient design for a certain lifetime may not be robust enough for a longer duration.

[64] To this respect, it may be observed that appropriate waste disposal is lawfully enforceable. Nevertheless, this is not easily done and could entail an additional cost on society.