# The contribution of data science applications to a green economy

*Data science driven applications (e.g., big data and artificial intelligence) can support the transition to a green economy. However, this requires overcoming existing barriers and providing appropriate framework conditions. Based on an analysis of 295 German and US start-ups using data science to create positive environmental impacts, we identify six main obstacles to a greater use of data science for sustainable transformation, and propose six measures that can be used to formulate policy recommendations.*

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**Abstract**
This paper examines the intersections between the hoped-for shift toward a green economy and data science (various forms of big data analytics and artificial intelligence). It does so through an analysis of data science applications with environmental relevance developed or deployed by German and US start-ups. The majority of the data science applications identified seek to improve the efficiency of existing products and processes, or to provide information. Applications that support more fundamental transformations of existing production and consumption patterns are fewer in number. To increase the sustainability-related impact of data science, it seems necessary to adjust policy framework conditions. Based on our findings, recommendations for action are presented regarding sustainability-related changes of the legal and regulatory framework conditions.

**Keywords**
artificial intelligence, big data, data science, green economy

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The term green economy was first used on the world stage in 2012 by UN Secretary-General Ban Ki-moon as an umbrella approach that brings together all economic policies relevant to sustainable development. Green economy is thus the guiding principle of an environmentally sustainable economy that combines ecology with social welfare-oriented growth (UNEP 2011).

A major development of the last decade has been the enormous increase in the availability of data across all manner of domains as well as technologies to analyze it. These include artificial intelligence (AI) and "big data" as well as the more standard statistical and descriptive approaches, collectively often referred to as "data science". This "data revolution" is widely perceived to promise significant economic and welfare gains (Manyika et al. 2011). An important question is whether and how data science, as well as digital technologies in general, also support the transition to a green economy. Growing literature on this topic can be divided into several strands. One strand studies the effects of the growth of digital technology on energy and resource use (Lange et al. 2020, Kern et al. 2018, Bordage et al. 2021). Another strand involves discourse analyses of relevant state policies (Kettenburg 2019). Finally, numerous studies catalog the environmental potentials as well as the risks of digitization and data science technologies like AI (Rolnick et al. 2019, Cowls et al. 2021, Vinuesa et al. 2020, WBGU 2019). These studies are mostly based on literature reviews of published scientific work and expert assessments. There has been little empirical research so far on how companies and other actors like state agencies and NGOs are using data science for sustainability purposes. This was a key question we examined as part of our project for the German Environment Agency (UBA) – *Interactions between the process of digitalization and the transition to a green economy* (Gotsch et al. 2022). The following summarizes some conclusions of this larger work, focusing on sustainability-related uses of data science by start-ups.

The transformation toward a green economy is accompanied and supported by new possibilities of digital change (WBGU 2019). Therefore, the influence of data science on the transformation process needs to be examined in more detail. However,

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it must be noted that private-sector activities and research work must always be seen in the context of the underlying political circumstances. Consequently, it is policy makers who set the regulatory framework within which private stakeholders may or may not contribute to the transformation of their behavior and help of new digital opportunities, depending on the incentives.

## The green economy

Transition to a green economy means changing the structure of institutions and mechanisms on several levels – macro, sectoral, company, and consumer. In principle, each of the three central sustainability strategies for a transition to a green economy – *efficiency, sufficiency,* and *consistency* – should be taken into account (Meyer 2020, Sühlmann-Faul 2020). The *efficiency strategy* aims at a relative reduction in resource consumption (Kahlenborn et al. 2019). The *sufficiency strategy* means changing existing production and consumption patterns in order to use less energy and raw materials in absolute terms. As a consequence, these behavioral changes then save resources (Heyen et al. 2013). The *consistency strategy* aims at a qualitative transformation of industrial material turnover in which the aggregate consumption level stays the same or even increases without endangering the environment (e. g., by switching to renewable energy sources) (Huber 2000).

The *efficiency strategy* seems to be the most readily compatible with current business models and regimes and could therefore be the easiest to implement. At the same time, the degree to which efficiency gains in themselves transform society and the economy toward a more sustainable one is probably limited. *Efficiency strategies* also carry the greatest risk of merely entrenching existing (unsustainable) structures and leading to rebound effects. Compared to the efficiency strategy, the *sufficiency strategy* promises significantly greater contributions to transformation, especially in the long term. However, the *sufficiency strategy* has a rather low sociocultural potential and it seems questionable whether sufficiency will ever be suitable for the mass market (Kahlenborn et al. 2019). The *consistency strategy* probably offers the greatest contribution to transformation in the long term. However, significant resistance and path dependencies (legal, economic, technological, organizational, and user-related) must first be overcome, which seems unlikely to be successful in all cases for a variety of reasons.

## Methodology

To understand the potential and current use of data science for the green economy, we constructed a unique data set of 295 German and US start-ups (226 US and 69 German companies), whose products and services (use cases) rely on data science and who claim to have a positive environmental impact. The data was collected from the *crunchbase.com* database and start-up accelerators, as well as from a detailed manual examination of each company's website.[1]

For each start-up, the professed positive environmental effects of its product/service were identified and categorized by its type of contribution to a green economy transition, as well as the sector or subsector where these effects are manifested. The basic assessment of the plausibility of the start-ups' environmental claims was based on the information provided on the company website and our own expertise and excluded any obviously doubtful cases. The professed environmental effects of each start-up's products/use cases were then coded according to whether they contributed to the *efficiency, sufficiency* or *consistency strategy*. The coding was done independently by three of the authors, with any differences in coding subsequently discussed and resolved.

We gave particular attention to start-ups due to their crucial role as incubators of new technologies and business models (Achleitner et al. 2019). However, as part of the larger project, we also examined use cases adopted by ten German and US companies, seven German and international environmental NGOs, and several European and US state agencies (results reported in Gotsch et al. 2022).

To better understand the potential and constraints of the use of data science in green economies (both by start-ups and by other actors like NGOs, state agencies, and other companies), we conducted 32 semistructured expert interviews with company executives, academics, civil servants, and NGO staffers. All interviewees had spent a minimum number of years in the fields of both data science and environment/sustainability. The questions varied somewhat according to the interviewee's expertise and professional position, but they generally covered the following points: how data science was currently used for sustainability purposes in the interviewee's sector, whether untapped potential existed, which data sources and data accessibility ocurred, and what the interviewee perceived as the main obstacles and limitations to a greater use of data science for environmental and sustainability purposes, including business, technological, regulatory, and market/customer-related obstacles. Conclusions derived from these interviews were then presented and refined at an expert workshop in late 2021.[2]

## Key findings regarding start-ups using data science to create positive environmental impacts

This section describes some of the main findings from our analysis of data science start-ups, including the sectoral distribution

1 For further detail on our methodology, see the online supplement: *https://doi.org/10.14512/gaia.32.S1.6.suppl*. In most of the use cases, the company website was the only data scource available.

2 Due to the UBA's interest, the interviews focused on the situation in Germany. We would like to thank all interviewees and workshop participants for their time. The views and analysis presented here solely reflect the authors' personal opinions and should not be attributed to any specific interviewee or workshop participant.

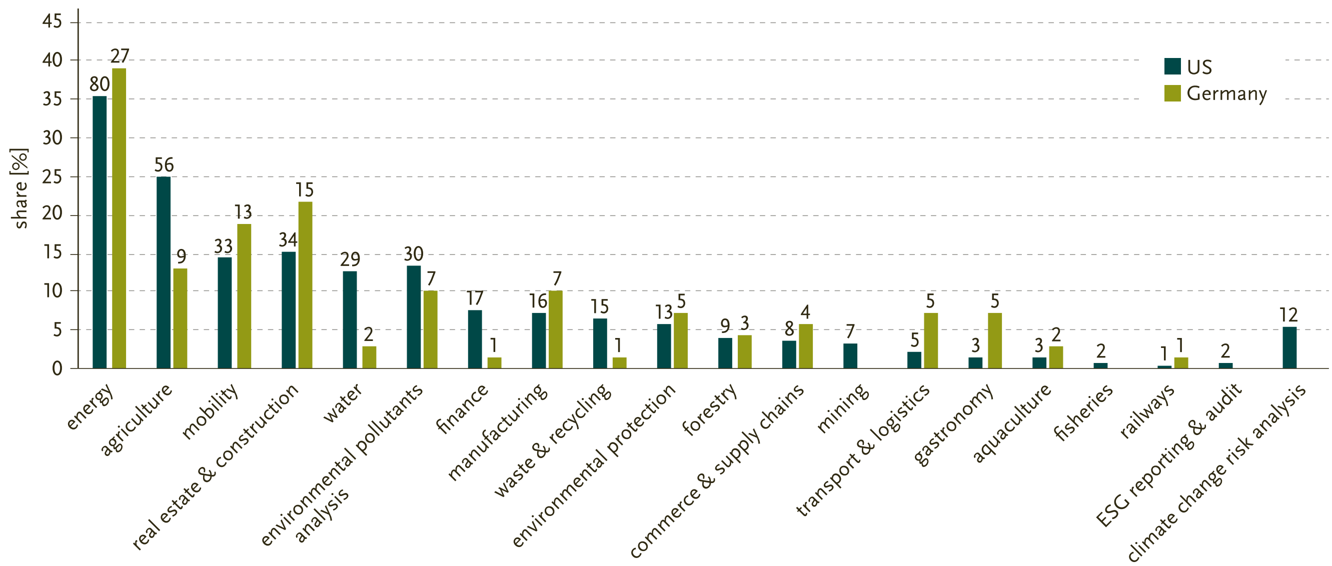


**FIGURE 1:** Sectoral distribution of data science start-ups in the United States (US) and Germany. Each start-up may be active in multiple sectors simultaneously (figures on the bars stand for the total number of start-ups). ESG: environmental social governance.

of US and German start-ups (figure 1). The figures in percents describe the share of German and American start-ups active in a given sector. Each start-up may be active in multiple sectors simultaneously; the sectors are based on the statistical classification of economic activities in the European Community (NACE).

There are several points which stand out. First, the sectoral distribution in both countries is quite similar. The main sectors in which start-ups are active include energy, agriculture, personal mobility, water industry, pollution monitoring, and real estate[3], followed by a long "tail" of sectors with only a few firms. As discussed in detail in Gotsch et al. (2022), this similarity also extends to the subsector level: in terms of numbers across the sectors, American and German start-ups tend to pursue similar applications and use cases. Typical use cases include realizing energy, water, fertilizer, herbicide/pesticide, and fuel savings; monitoring air and water pollutants and greenhouse gas emissions; optimizing the deployment, operation and maintenance, and grid integration of renewable energy and electric vehicles; and improving public transport. The sectoral focus and use cases of the multinationals examined are similar to those of start-ups (Gotsch et al. 2022).

Second, a corollary of the comparable sectoral distribution is that there seem to be few "blank spots", that is, sectors or use cases dominated far more heavily by firms from one country or the other. At least in the field of developing environmentally oriented data science applications, there is no obvious evidence that German companies lag behind American ones.[4]

Third, however, there are a few sectors where US start-ups are significantly more active: namely, agriculture, water, finance, waste/recycling, and analysis and forecast of climate change risks. The expert interviews indicated mostly sector-specific reasons for these divergences, that is, they do not indicate a more general, systemic weakness in the German innovation system for environmentally oriented data science. For example, different agricultural structures (field and farm sizes, crop types) and differences in the levels of water stress and better water infrastructure mean that the business cases for many data science-based precision agriculture and water management applications may be weaker in Germany than in America. Similarly, much of the practical climate-risk analysis commercialized by start-ups in the US is performed by applied research institutes in Germany that have no direct US equivalent.

We next sought to categorize the products and use cases developed by the start-ups according to the type of contribution they made to a green economy transition in order to draw conclusions about whether they were contributing to *efficiency, sufficiency,* or *consistency strategies*. Inductively, we arrived at five broad classes of products/use cases (figure 2, p. 32). About 55% of start-ups in both countries offer products that promise efficiency improvements within the context of existing modes of production and consumption (e.g., precision agriculture, water, or energy savings). These correspond most clearly to the *efficiency strategy*. A smaller proportion of firms, 32% in Germany and 37% in the US, are developing products that directly implement or fundamentally support new and more sustainable systems (e.g., renewable energy, circular materials economy, organic or urban vertical agriculture, and mobility systems built around public transport, electric vehicles, sharing and walking/cycling). >

3 Many of the firms active in real estate are essentially energy and water services companies focused on realizing efficiency savings in buildings.

4 While we identified more than three times as many American start-ups as German ones, this must be considered in the context of the US economy being more than five times the size of the German one.

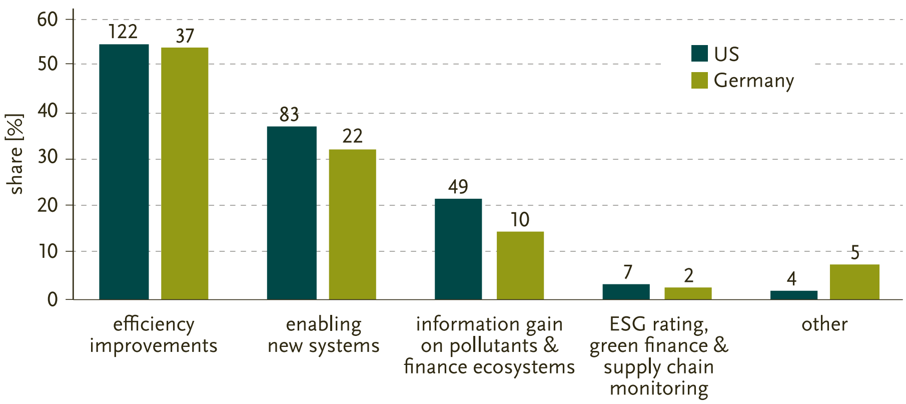


**FIGURE 2:** Types of use cases pursued by data science start-ups in the United States (US) and Germany. ESG: environmental social governance.

These correspond to the consistency strategy. Importantly, data science start-ups hardly ever try to implement sociotechnical systems such as these in their entirety. Instead, they tend to offer specialist products that support particular aspects of these systems (e.g., automated operation and management for wind turbines with drones and AI). Especially in the energy sector, many companies offer solutions to improve both efficiency and new systems (e.g., energy management software to reduce consumption and improve the grid interaction of self-produced renewable energy).

In addition, 14% (Germany) and 22% (US) of the start-ups offer solutions that mainly provide information (data, analysis) about pollution (e.g., air, water, soil, greenhouse gas), ecosystems (e.g., tree cover, composition of fauna/flora populations), or geophysical processes (e.g., wildfires, climate change). These correspond to either *efficiency* or *consistency strategies,* since high-quality data and analyses on pollution, ecosystems, or climate change are necessary for both. There are also many start-ups in this field that are pursuing both "new systems" and "efficiency" use cases (e.g., a start-up specializing in earth observation data analyses could offer specific products for monitoring methane emissions, identifying optimal sites for solar power, and optimizing fertilizer use in precision agriculture).

Both in Germany and the US, some 3% of start-ups offer products for corporate environmental social governance (ESG) ratings, sustainable finance (i.e., "green" investment ratings and portfolios), and supply chain monitoring. These use cases are also arguably in line with both the *efficiency* and *consistency strategies.* At present, these products mainly promote efficiency (output per unit of pollution/resource consumption). However, in the longer term, the information they generate and the incentives they help to create for corporations may very well promote the qualitative change in production and financial systems implied by the *consistency strategy.*

Finally, 2% (US) and 7% (Germany) of start-ups offer various kinds of "other" products (e.g., apps to help guide personal consumption by providing information on the carbon footprints of products or analytics systems for corporate users to help prevent industrial accidents). Most of these do not clearly correspond to any of the three strategies.

In summary, we found that the largest number of start-ups in both countries offer solutions that mainly support *efficiency strategies,*[5] while about a third have products that directly support *consistency strategies.* Around 20% have products that would support either strategy. Finally, none of the start-ups seem to develop products that clearly correspond to *sufficiency strategies.* Arguably, this should not come as a surprise: efficiency use cases are highly consistent with existing business logic (the cost reduction imperative) and should therefore be relatively easy to justify to potential clients. AI and big data are also well-suited to sieving through huge reams of data to find efficiency gains. Conversely, it seems that the absolute, not just relative, reduction in consumption that *sufficiency strategies* require is most at odds with conventional business logic and the imperative of companies, including start-ups, to consistently increase their revenue. Therefore, the fact that none of the start-ups appears to be developing products in line with this strategy is not unexpected.

Finally, the broad-based systems transformation that is implicit in the idea of *consistency strategies* entails a multitude of complex technological, organizational, and business challenges, and it should thus create large numbers of new business opportunities. It is therefore not surprising that we see significant numbers of start-ups developing such products. At the same time, products that support genuinely new systems can be particularly challenging, both technologically and in business terms, since the systems themselves are still in the process of emerging. Therefore, it is perhaps not surprising that the number of companies in this field is somewhat smaller than those pursuing the more straightforward efficiency cases.

## Results of the study

In order to identify the biggest obstacles to the greater use of data science for a green economy, we systematized the various obstacles that emerged from our analysis of the start-up data set and the expert interviews, according to whether they related to business, technological, regulatory, or market/customer factors. We validated these findings in a workshop with selected experts, in which we presented the different obstacles identified in our interviews and analyses, and asked the experts to assess and comment on the relevance and prevalence of these obstacles.

5 For similar findings in the research community see Santarius and Wagner (2023, in this issue).

According to our results, the biggest obstacles in Germany to the greater use of data science for the green economy, both by start-ups and other actors (e.g., small and medium sized enterprises, non-governmental organizations, and state agencies), lie in the areas of 1. data availability and data quality, 2. data access, 3. data infrastructures, 4. lack of understanding of the possibilities and limitations of digital technologies, 5. regulatory hurdles, and 6. cost-ineffectiveness and insufficient uptake.

1 ***Data availability and data quality.*** The necessary data are not available. The reasons are often of a general nature (e.g., a lack of economic incentives to invest time in creating and processing data). The creation of good digital data sets not only requires appropriate technical equipment (e.g., sensors) but also considerable domain knowledge.

2 ***Data access.*** Even if data are available in a digital format, they are not always accessible. For private data, there are concerns about leaking trade secrets. For publicly available data, awareness of open data has grown but is not yet universally applied. It is still difficult to find out which government agency (and which department within that agency) actually collects certain data, where these data are located, and who to contact to obtain them.

3 ***Data infrastructures.*** Data science requires powerful IT infrastructures to merge, store, and process data. Start-ups, in particular, may struggle to access the necessary infrastructure and equipment. Use cases such as the circular economy, which require extensive data sharing across companies and sectors, present a particular challenge. Often, the infrastructure required to enable such data sharing does not exist. Building a suitable infrastructure often requires not only investments in hardware but also in personnel (jobs, training, etc.), as well as extensive interorganizational coordination.

4 ***Lack of understanding of the possibilities and limitations of digital technologies.*** Non-governmental organizations and small and medium sized enterprises usually do not have the financial resources that would enable them to build strong data science departments. Specialists and executives in companies, municipalities, and NGOs often lack a sound understanding of the possible uses and limits of the technology in their domains. Conversely, data scientists and AI experts in universities and research institutes often lack a deeper understanding of the specific problems and framework conditions of the respective domains.

5 ***Regulatory hurdles.*** In most of the domains relevant to a green economy, there are complex, domain-specific regulatory frameworks with numerous detailed regulations. In addition, most green economy-relevant domains belong to the area of critical infrastructure with high security requirements, where regulatory adjustments can only be made with caution. Specific difficulties lie mostly in the details of individual domain-specific regulations, which create barriers to data access and use.

6 ***Cost-ineffectiveness and insufficient uptake.*** Without a common vision for the future that provides a framework, developments will take place in a variety of directions. This will lead to uncertainty among private-sector actors with regard to investments. Environmental potential can only be harnessed within a framework where the boundaries and goals are clear.

Overall, it is apparent that only a few of the obstacles mentioned are directly related to environmental regulation, which means that the majority of obstacles cannot be solved by the activities of the environment ministry or its subordinate authorities alone. Therefore, solutions can probably only be found in coordination with all the respective political actors and stakeholder groups involved.

## Conclusion and policy recommendations

The data science applications analyzed revealed multiple examples of applications for a green economy. However, most of these applications aim to improve the efficiency of existing production paradigms or to provide additional information. This shows that it is crucial to actively refocus the purpose of digital transformation and develop shared visions, values, and goals for sustainable development in the digital age.

The findings of this paper can be used to formulate policy recommendations that can provide a framework for overcoming barriers and integrating digital technologies on the path to a green economy. They will be discussed in ongoing policy processes and in the multistakeholder group *Coalition for Digital Environmental Sustainability (CODES)* (2022), a global alliance of governments, businesses, and civil society.[6]

According to the authors of this paper, the following six measures can help overcome obstacles and support a greater use of data science for green transformation.

1 With regard to ***data availability and data quality,*** data experts perts and domain actors should be consulted to assess whether the publicly funded creation of high-quality reference data sets makes sense. There should be a clear prioritization of the domains and application clusters for which these reference data sets would be created. Public research funding could also provide more support for the creation and publication of high-quality data sets.

2 ***Improved access to*** data could be created through economic incentives, which would make data sharing more attractive to private actors. The development of technical solutions that en-

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6 *www.sparkblue.org/CODES*

able data processing under high-security guarantees and without access to nonanonymized data should also be supported. The implementation of open data in the public sector needs to be further strengthened in order to improve the ability to find existing data. The German National Research Data Infrastructure[7] has begun to close these gaps, but there is still a need for further action.

3 In order to create the necessary ***data infrastructure,*** public funding could be provided for modern data technology for start-ups or NGOs. The establishment of government institutions (which has already begun, for example, in Germany with the National Environmental Information Centre,[8] the Artificial Intelligence Laboratory for Sustainability Solutions,[9] or the National Center for Monitoring Biodiversity[10]) can create new data infrastructures for sustainable solutions. This also strengthens environmental governance through digital tools. In order to use the emerging transformation dynamics through digitalization for the ecological transformation ("double transformation"), environmental governance needs new structures, processes, and competencies to effectively use and shape the new technologies.

4 There are already several initiatives to promote a ***better understanding of the possibilities and limits of digital technologies.*** These initiatives (such as the community *Sustainable Digitalization*[11] of the German Federal Environment Ministry or the *Bits & Bäume*[12] initiative) need to be strengthened further, but beyond that, there should be targeted research into what the explicit hurdles to networking are and how they can be best addressed. In order to raise awareness about the possibilities of digital technologies, workshops could be offered (e. g., with foreign stakeholders who have been using these technologies for a long time and on a larger scale, as well as with application-oriented scientists). These workshops could also be organized for small- and medium-sized companies in selected domains. Within the framework of government research funding for sustainable data science applications, there should be more calls for applied research aimed at cooperation and consortia building between start-ups, research institutions, and NGOs in order to institutionalize the exchange. A successful example of this can be seen in the *AI Lighthouse Projects for the Environment, Climate, Nature and Resources* intiative, which is funded by the German Federal Environment Ministry.[13]

5 In order to overcome existing ***regulatory hurdles,*** the use of regulatory sandboxes and living labs should be further promoted – in which existing rules and regulations are temporarily suspended and if appropriate, regulations are subsequently adjusted in light of the knowledge gained. In general, future regulatory projects should, if possible, be provided with exception and experimentation clauses in order to support the nonbureaucratic implementation of sandboxes and living labs. Within this framework, controlled access to real, critical, or personalized data could then be enabled in order to identify which precise aspects have to be regulated. In future revisions of data protection law, public interest in increased data use for the transition to a green economy should be given greater consideration. For example, stronger enabling structures should be enshrined in the law and public interest in data use should be more institutionally anchored. This should be considered part of the upcoming implementation of legislative initiatives of the European Union on an international level, for example, the *Digital Services Act* (Regulation [EU] 2022/2065) or the *Digital Markets Act* (Regulation [EU] 2022/1925).

6 In order to provide an ***appropriate framework for real transformation,*** the economic viability and acceptance of sustainable digital applications in particular would have to be strengthened. This may require a coordinated government intervention in the form of a framework for a vision of the future. A good example of this is the *Natural.Digital.Sustainable* action plan of the German Federal Ministry of Education and Research.[14] This intervention should be a coordinated, concerted mix of financial incentives, subsidies, sensible regulation, and, if necessary, an expansion of transparency, testing, and due diligence obligations and bans. For example, a mission-oriented innovation policy seems suitable for this purpose, as it could provide and coordinate the necessary framework.

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