WORLD BANK GROUP

PPIAF Enabling Infrastructure Investment

PPP Contracts in An Age of Disruption

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Defined Terms and Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
AV	Autonomous Vehicle
ATC	Alternative Technical Concept
BIM	Building Information Modeling
CAD	Computer-Aided Design
CAPEX	Capital Expenditure
contracting authority	Public Authority That Enters Into The Ppp Contract With The Private Partner
CSP	Concentrated Solar Power
EC	European Commission
ECB	European Central Bank
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
GHG	Greenhouse Gas
GRID	Green, Resilient, and Inclusive Development
GW	Gigawatt
ICT	Information and Communication Technology
IMF	International Monetary Fund
IFI	International Financial Institution
IoT	Internet of Things
IPP	Independent Power Producer
IRR	Internal Rate of Return
ITS	Intelligent Transport System
LCOE	Levelized Cost Of Electricity
MAGA	Material Adverse Government Action
MI	Mobile Internet
ML	Machine Learning
MR	Mixed Reality

NDC	Nationally Determined Contribution
OPEX	Operating Expenses
PPP	Public-Private Partnership
PPP contract	Long-Term Contract Between a Private Party and a Government Entity, for Providing a Public Asset or Service, in Which The Private Party Bears Significant Risk and Management Responsibility, and Remuneration is Linked to Performance
PV	Photovoltaic
private partner	Private Company That Enters Into The Ppp Contract With The Contracting Authority
RFP	Request For Proposal
TWh	Terawatt-Hour
UAV	Unmanned Aerial Vehicle
UNFCCC	United Nations Framework Convention On Climate Change
V2B	Vehicle To Building
V2G	Vehicle To Grid
V2H	Vehicle To Home
V2I	Vehicle To Infrastructure
V2V	Vehicle To Vehicle
V2X	Vehicle To Everything
VfM	Value For Money
VGI	Vehicle To Infrastructure
VR	Virtual Reality
WPT	Wireless Power Transfer

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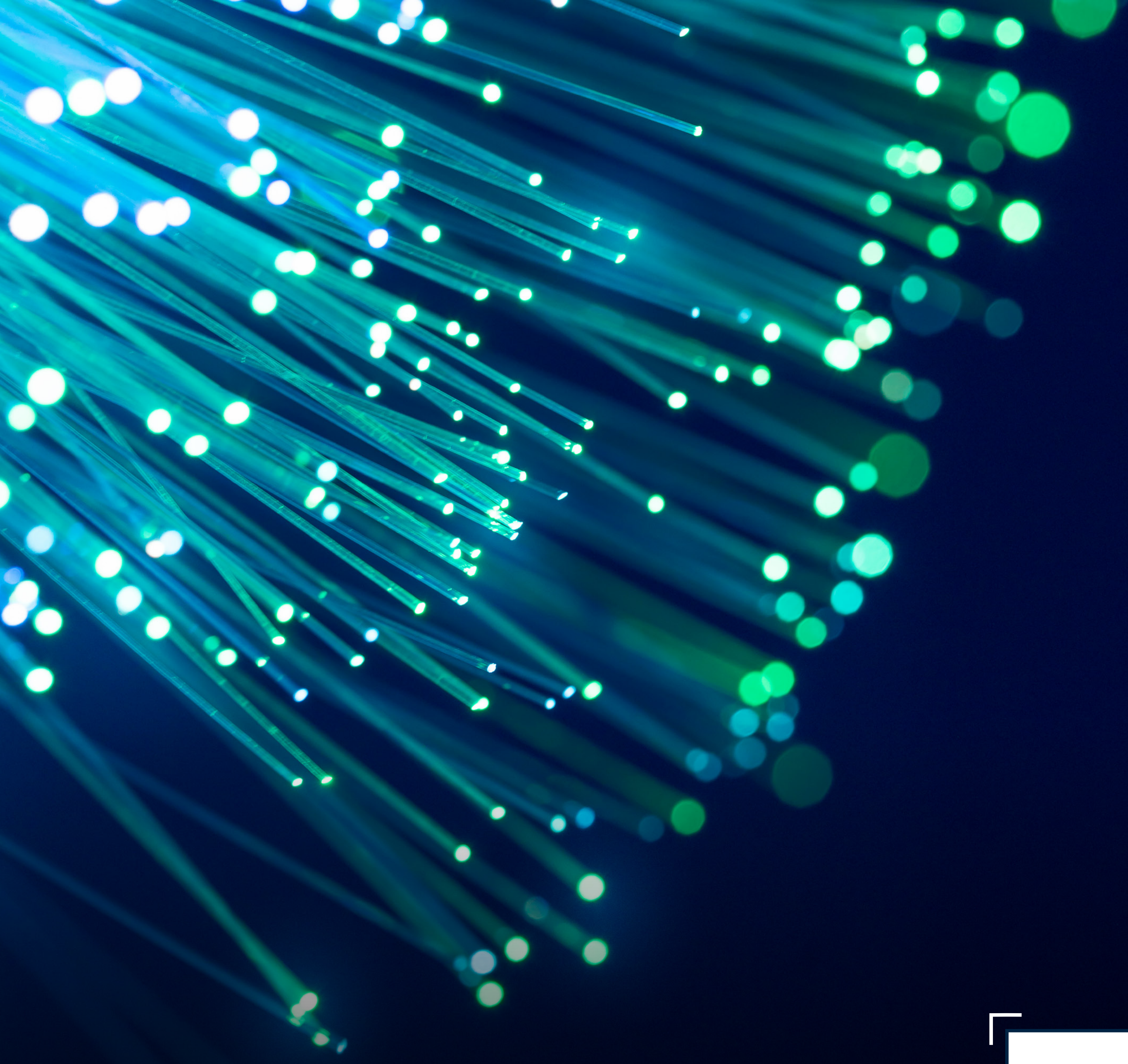


Executive Summary

Executive Summary

"To improve is to change; to be perfect is to change often." —Winston Churchill

This report examines how disruptive technologies impact public-private partnership (PPP) infrastructure; what this means for the management of existing PPP contracts; and how better partnerships can be created—ones that are more resilient to such changes, as well as flexible enough to encourage collaboration between the public and private sectors in order to allow implementation of innovative technologies.

Context and Aim of the Report

Both innovation and PPPs can be essential drivers to get more quality infrastructure services to more people: New technologies can maximize the positive impact of infrastructure by enhancing sustainability, resilience, and economic efficiencies, and they can play an important role in helping economies respond to global crises. At the same time, emerging technologies have the potential to disrupt PPP infrastructure models if certain equipment, delivery models, and development tools become increasingly outdated or inadequate before public or private investors can fully recover their costs.

The objective of this report is to help governments of emerging economies to better understand the increasing impact of disruptive technologies on PPP infrastructure projects. The report also seeks to provide guidance on how to manage existing PPP contracts and design future ones at a time when emerging technologies are providing opportunities for innovation, and new business models can be essential for economic growth and private sector development in emerging markets. In addition, the report intends to encourage further debate among stakeholders involved in PPP projects about the scope and type of technological disruption they have encountered, as well as approaches to manage associated risks and to encourage innovation.

Disruptive Technology, Infrastructure and PPPs

Disruption is all around us. Changes to the status quo are not new; they can come slowly or suddenly, and they can be beneficial, disastrous, or both. However, **with the advent of new technologies**, technological **change has scaled with ever-increasing speed across the global economy**. Though it is uncertain what types of disruptions PPP infrastructure projects will encounter in the future, it is already apparent that disruption through technological change will continue. Such change will create promising opportunities for the development and implementation of infrastructure—in particular in emerging markets—but it will also disrupt infrastructure sectors and projects. This can be disconcerting when applied to long-term contracts for infrastructure development, which rely on assumptions and models developed at the beginning of a project for a period of years or even decades.

Developments in the energy sector give an idea of the scope and dynamic of the potential disruptions that are underway. For example, the rapid pace of developments in the renewable energy space, and corresponding policy changes, have opened up several arbitration cases and countless renegotiations. Similarly, advances in battery storage, artificial intelligence, electric and autonomous vehicles, internet of things (IoT), and other disruptive technologies promise to change the context in which long term PPP contracts have been drafted.

Disruptive technologies present extraordinary opportunities for progress, with cleaner, more efficient, and more resilient infrastructure services. These opportunities should be seized and celebrated. However, changes from the status quo create pain points that must be carefully managed, in particular when long-term PPP contracts are structured based on a financial model on which financing relies. Unraveling such commitments has proven contentious and difficult.

The discussion of disruptive technology and its impacts on PPPs can be considered in the broader context of disruptions that have in recent years increased, and that present unprecedented worldwide challenges, such as climate change, natural disasters, economic crises, and global pandemics such as COVID-19. Unlike these disruptive events, which usually have negative consequences, disruptive technologies generally indicate progress, albeit often with winners and losers. Even though the nature of disruptive events and disruptive technologies differs, useful guidance can be drawn from the global experience of the impact of disruptive events on PPPs; analysis of underlying issues, occurrences, and impacts of risks and ways to address them; and tools that have been developed to deal with the growing number of disruptive events in the context of PPPs. The lessons learned, and approaches that have been discussed or implemented with regard to specific disruptive events, provide a useful basis for the development of guidelines aiming to enhance resilience of PPP contracts and contract management in the context of the exponential pace of technological change.

Enhancing "'Innovation Resilience'" and the Adoption of Disruptive Technology throughout the PPP Project Cycle

Preparing for disruption, including by disruptive technology, starts well before the contract stage, during project selection and preparation. It is therefore important for policy makers and investors to not only consider the existing legal framework but also the policy trajectory years into the future. **Taking the long view when screening and selecting projects** is essential, to avoid assets becoming "stranded" well before the end of their economic life (in some cases, even before they are operational). This involves improved forecasting of disruptive technologies, and reading policy signals before they become policy changes.

For example, commitments made during the 2015 Paris Agreement on Climate Change are still being put into more detailed action plans around the world, but it should not be surprising that countries are becoming more aware of and responsive to the global climate crisis. This is a trend that has been occurring for the last decade. Therefore, it is important when selecting projects now to **prioritize "green" and resilient infrastructure**—not only to prevent and respond to climate-related shocks and stresses, but also to ensure sustainability of support for the projects in the years to come, and to avoid the risk of stranded assets. Conducting proper due diligence before investment is an obligation on the part of the private investor as well as the public entity, in order to set realistic expectations regarding what will stay constant, and what may change.

Flexibility with respect to technological changes can be embedded during the **project appraisal stage**, when the risk allocation and scenarios are modeled, as well as the **procurement stage**, by ensuring that the request for proposals allows bidders to propose the latest innovative solutions, and by factoring such innovations into the scoring. Governments should encourage innovative practices in the procurement documents and bidding methods, i.e., a two-stage bidding process that allows bidders to compete on innovative design aspects before financial considerations enter the picture. In the US state of Maryland, for example, procurement of a new metro line was done in phases, complemented by an innovative dialogue process that allowed innovations proposed by bidders to be taken into account during the project design and tendering phases.

When **drafting PPP contracts**, it is important to ensure that the output specifications consider long-term needs and anticipate changes that are reasonably predictable. This will need to be balanced with ensuring that the private partner can quantify its risk through caps or exceptions. Upgrades with major cost implications can then be treated as variations that are compensated. An appropriate gain sharing mechanism can incentivize the adoption of superior technology if it becomes available, while ensuring that contracting authorities and society at large benefit from efficiencies that are made possible by disruptive technologies. In Australia, technological upgrades to a desalination plant could be proposed by either the public or private parties to the PPP. If proposed by the public party, the authority pays for the upgrade but also keeps any resulting cost savings. If proposed by the private party, it would share in the cost savings, creating an incentive to make such improvements. In general, balance of interest considerations should guide PPP contract management. For example, if a technological development and the need for a requested technological upgrade were unforeseeable at the time the parties entered into the contract, and such an upgrade requires significant investment, it may be more appropriate to treat the request as a contract variation if the wording of the PPP contract is not explicit.

One way to mitigate exogenous demand risk is to structure PPP contracts as **present value-of-revenue (PVR) contracts**. In general, it would be advisable to switch to shorter terms or make contractual terms more flexible in sectors that are susceptible to technological change, should the financial model allow. Contracting authorities could also consider **extending provisions that make tariffs or payments dependent on specific formulas** in tariff adjustment schemes, to factor in economic effects caused by technological disruption and to incentivize innovation.

To protect parties from **scenarios in which disruptive technology upsets the economic balance** of the PPP contract, it will be important to carefully assess and allocate potential increased risks related to such technology, and to clearly define atypical and extreme events that should fall within the ambit of provisions, together with thresholds, exceptions (where appropriate), and consequences for each risk. The contract could, for example, expressly mention cyber attacks as force majeure events, together with required precautionary and mitigation measures. It can also be advisable to **spell out legal concepts** that govern a PPP contract in a specific jurisdiction and allow for a **rebalancing of the economic equilibrium** of the PPP contract to achieve more clarity for both parties. Depending on the circumstances, equitable principles could also be integrated into PPP contracts in jurisdictions where such principles are not mandated by law, to provide better protection for both parties in an environment that is continuously changing due to technological advances.

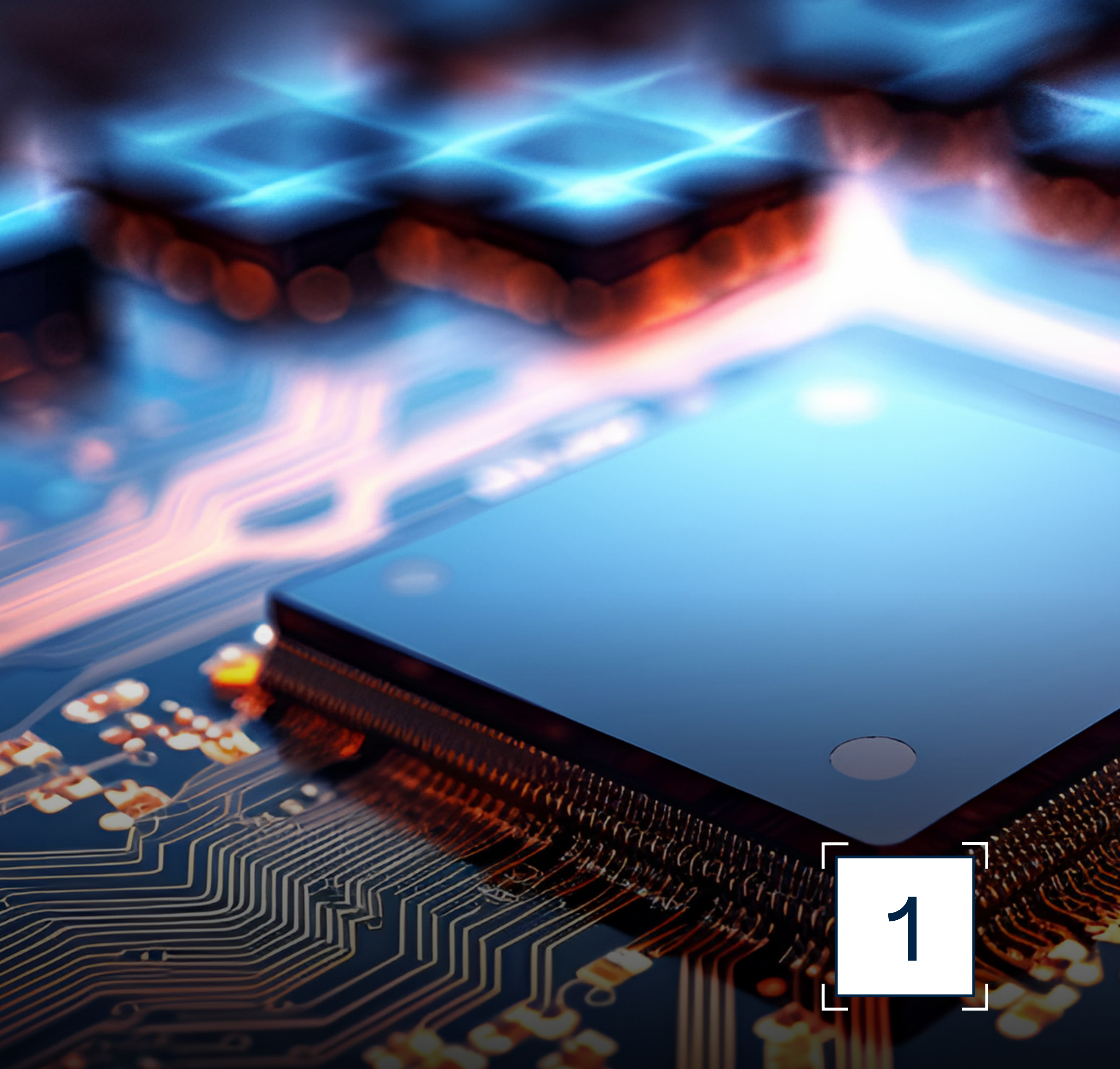
The level of risk the private partner can assume with regard to disruptive events is closely connected to the **availability of insurance**. Contracting authorities should review recent developments in the insurance market, and should take into account the availability of insurance for events or developments that may occur more frequently due to disruptive technology (e.g., cyber incidents) and the cost of such insurance. As a general rule, uninsurable disruptions are more likely to be treated as force majeure or material adverse government action (MAGA) events, whereas the private partner may be able to assume the risk for impacts caused by certain disruptions that can be covered by insurance mechanisms.

Good contract management, including cultivating strong relationships with the partner and stakeholders, helps lead to amicable discussions when things change, before any disputes arise. To deal with conflicts that may occur more frequently in times of increased disruption, PPP contracts should contain well-drafted dispute resolution clauses. Alternative dispute resolution mechanisms, including the use of dispute review boards, can be particularly useful tools to prevent and resolve conflicts arising in the context of disruptive technology, because they allow the parties to settle disputes informally at an early stage, before they become real disputes or impede the contracts.

In particular, in instances where a technological disruption has fundamentally altered circumstances long term, renegotiations can be the best path forward to try to find a mutually acceptable solution to an unforeseen problem or opportunity. Although renegotiation should be used sparingly and avoided where possible—because it harms the investment climate of the country and jeopardizes the transparency and competitiveness of the procurement—in some instances it is the preferred solution. Sometimes there may even be a mutually beneficial outcome to renegotiation, in which case it makes sense to adjust the contract to benefit from that outcome, for example if there is a technology that improves the efficiency of the project. PPP contracts should expressly regulate the processes and conditions for renegotiation, in particular if the PPP framework does not contain detailed mandatory requirements for contract renegotiation. At a minimum, these provisions should provide for third-party government approval. Amicable renegotiation is possible, if there is trust between the public and private parties and if the renegotiated terms are seen as fair to both sides. In Puerto Rico, for example, renegotiations resulted in an extension of the concessional term, increases in the private party's share of revenues, and additional payments, which helped the private party accept the financial burden of additional technological improvement. In other instances, if there is a strong enough public policy reason not to continue with the contract, **termination** combined with renegotiation of the terms may be the only option, understanding that the investor has the right to demand all of the termination compensation to which it is entitled under the contract in the case of voluntary termination.

Ultimately, however, a long-term PPP contract will be limited in how much flexibility can be introduced without threatening its bankability. PPP projects are by nature dependent on a set financial model at the outset to raise financing for the upfront construction costs. Once that financing is committed, it is very difficult to adjust any variables or assumptions in the model, and attempts to do so almost inevitably result in renegotiations or disputes.

Overall, a healthy underlying sector with competitive forces driving innovation and pricing helps to encourage adoption of new technologies. A financially robust underlying sector also helps to raise the financing and funding needed to make key technological shifts going forward, such as retiring old "dirty" technologies to make space for cleaner ones. Encouraging market-based pricing where possible (for example, some liberalized markets for electricity) could naturally reflect and drive innovative behavior, helping to introduce flexibility—though whether that is a desirable outcome for every publicly regulated infrastructure sector is debatable.



1

Context and Aim of the Report

1. Context and Aim of the Report

1.1. Context

Building modern, sustainable, affordable, and resilient infrastructure is critical for meeting the rising demands of billions of people around the globe, while addressing global threats such as climate change. Both technological innovation and PPPs can be essential drivers to close the infrastructure gap and get more quality infrastructure services to more people: They can maximize the positive impact of infrastructure by enhancing sustainability, resilience, and economic efficiencies, and they have the potential to accelerate economic growth and private sector development in emerging markets. At the same time, insufficient public budgets (exacerbated by the COVID-19 pandemic) and the quest for greener, more resilient and inclusive infrastructure projects[1] continue to generate interest in public-private-partnerships (PPPs) globally.

The increasing number of global disruptions—in particular the growing frequency and intensity of climate-related and other natural disasters worldwide, economic and financial crises, and the pandemic—have, however, demonstrated some of the vulnerabilities and risks associated with unforeseen disruptive events on long-term infrastructure PPP contracts and the related importance of making PPPs more resilient. In this context, fast-paced technological and scientific advances can also be viewed as a threat. The advent of the Fourth Industrial Revolution has the potential to disrupt PPP infrastructure models if certain equipment, delivery models, and development tools become outdated or inadequate before public or private investors can fully recover the costs of the infrastructure. Similarly, deepening understanding of climate science and subsequent global collective action are rapidly pushing governments and companies away from carbon-intensive assets and industries and towards "clean" ones, raising the question of how to retire existing "dirty" assets. These impacts are already being felt in countries around the world, including in public services sectors such as transport and energy.

How can private sector adoption of emerging technologies be supported within existing and future PPP projects? How can new technologies be harnessed to strengthen PPP projects going forward? Which parties should bear the burden of the risk of obsolete and stranded assets? And how can governments "future-proof" their pipeline PPPs?

This report addresses these questions systematically by (i) defining disruptive technologies and their potential impacts on infrastructure projects and PPP contracts; (ii) outlining different policy options during the project development phase that encourage private sector adoption of innovative technology while improving resilience towards technological disruption; and (iii) discussing considerations for PPP contract management as well as future contracts to embed flexibility that allows for the integration of new technologies and accounts for technology disruptions that will inevitably occur.

1.2. Aim of the Report

The objective of this report is to help governments of emerging economies to better understand the increasing impact of disruptive technologies on PPP infrastructure projects, and to provide guidance on how to manage existing and design future PPP contracts. This comes at a time when emerging technologies are creating opportunities for innovation and enabling new business models that can be essential for economic growth and private sector expansion, and also have the potential to disrupt the way we plan, develop, deliver, operate and use infrastructure.

[1] The report *Green, Resilient, and Inclusive Development* (World Bank Group 2021) charts out the Green, Resilient, and Inclusive Development (GRID) approach, which departs from previous development strategies by promoting economic growth that goes hand in hand with environmental goals and social inclusion.

This report looks specifically at infrastructure projects that are financed through the PPP model because disruptive innovation affects them differently than traditionally procured infrastructure contracts in terms of challenges and opportunities. In projects that are entirely publicly funded, governments can unilaterally decide how to deal with changing economic assumptions, technological advancements, and standards. Projects that are financed through PPP arrangements are less flexible because of the long-term commitments made between the parties, including lenders. These long-term partnerships are based on key commercial assumptions, performance requirements, and an allocation of risks and related costs, all of which make it more difficult to respond to unexpected disruptions.

The report presents emerging practices related to PPP projects in developed and developing countries that were impacted by disruption over the past few decades. These examples as well as case studies[2] provide an understanding of the scope and type of pressures that PPP contracts are faced with when disruptions occur. They reveal trends related to the effectiveness of PPP contractual and legal mechanisms in responding to disruption in different sectors, and scenarios that can inform PPP contracts—both the management of existing contracts and the design of future ones. Recognizing that new trends are emerging continuously while disruptive technology is spreading rapidly, this report also intends to encourage further debate among all stakeholders involved in PPP projects—about potential technological disruptions and their impact on infrastructure PPPs, as well as approaches they have encountered that facilitate the adoption of innovative technology and the management of the risk of obsolescence.

Disruptive Technology Versus Disruptive Event

For the purpose of this report, two distinct types of disruption are distinguished:

- The term **disruptive technology (or disruptive innovation)** refers to technological advancements that
  - Enhance infrastructure development, delivery, and operation, and/or
  - Make PPP projects less attractive, either because the new technological opportunity requires high upfront cost or makes PPP projects obsolete.
- The term **disruptive events** refers to natural and man-made disasters, including those caused by climate change or cyber attacks, and economic and financial crises. A recent example is the COVID-19 global pandemic that has disrupted the world economy and has had a disastrous impact on certain sectors.

[2] Included in Section 6 are five case studies that illustrate how different categories of technology disruption and disruptive events were dealt with in various PPP projects and what good practices might entail. These practical examples are drawn from different sectors and from both developed and developing countries globally.

2

Disruptive Technology, Infrastructure and PPPs

2. Disruptive Technology, Infrastructure and PPPs

2.1. What Is Disruptive Technology?

Technological developments have always transformed lives and disrupted old ways of doing things. Older technologies, like the telephone, developed gradually, over decades. In contrast, new technologies, like the cell phone, scale with ever-increasing speed across the global economy. Often a few different new technologies (e.g., artificial intelligence, IoT, 3D printing, robotics) come together to create something entirely new. Although specific types of disruption caused by innovation are difficult to predict with precision, it has already become clear that these new technologies will have significant economic impact and will fundamentally change the way people around the globe work, live, conduct business and interact with each other.

However, not every new technology or innovation is disruptive. The original meaning of disruption is an occurrence of something external from a system, process, or event that prevents it from continuing as usual or as expected. Today, the term disruptive technology (or disruptive innovation) has become a trendy phrase to describe transformative change.[3] The phrase is used for technological advancements and innovations that share the following characteristics:

- The technology is rapidly advancing.
- The potential scope of impact is broad.
- Significant economic value could be affected.
- It has the potential to dramatically change the status quo.

The World Bank defines "disruptive and transformative technologies" in its 2019 Development Committee paper[4] as those that result in a step change in the access to products and services, and dramatically alter how we gather information, make products, and interact. For the purpose of this report, the terms "disruptive technology" and "disruptive innovation" are used interchangeably and in this broad sense.[5]

[3] The concept of disruptive technology (and later disruptive innovation) was originally introduced in 1995 by Clayton M. Christensen, and describes the evolutionary process of a product or service that is initially inferior to what is offered in established markets and only useful to new, emerging markets or smaller, low-end, and often overlooked markets. The product or service then migrates into and dominates the established markets by adapting to deliver the performance and value that the consumers in the established markets demand.

[4] World Bank Group. 2019. *Mainstreaming the Approach to Disruptive and Transformative Technologies at the World Bank Group.* See also: World Bank Group. 2018. *Disruptive Technologies and the World Bank Group—Creating Opportunities—Mitigating Risks.*

[5] According to the 2017 Organisation for Economic Co-operation and Development (OECD) report *Selected Good Practices for Risk Allocation and Mitigation in Infrastructure in APEC Economies,* disruptive technology risk is the risk that a new or emerging technology unexpectedly displaces an established technology used in that sector. Such technological changes can cause significant disruption to a project over the term of a concession.

2.2. Examples of Disruptive Technologies that Could Transform Infrastructure

Technologies that have the potential to revolutionize or that have already impacted infrastructure projects include the following:[6]

- Renewable energy
- Stationary and mobile energy storage devices
- Mobile Internet (MI)
- Artificial Intelligence (AI)
- Mixed Reality (MR), Virtual Reality (VR), and Augmented Reality (AR)
- Big data
- Blockchain
- Robotics
- Internet of things (IoT)
- 3D printing
- Advanced materials

This list is not meant to be exhaustive, and new technologies that have the potential to significantly affect infrastructure continue to appear. Appendix A provides an overview of these disruptive technologies, with a generic definition of each of these technologies and how they are applied to infrastructure.[7] Based on this, the following section (2.3) deals with the impact of disruptive technologies on PPP infrastructure projects.

2.3. How Are Infrastructure PPPs Impacted by Disruptive Technology?

Disruptive innovation has already impacted infrastructure projects worldwide, especially in the energy, information and communications technology (ICT), and transport sectors. This development is expected to intensify in coming years because more and more disruptive innovation will be integrated throughout the entire project life cycle of infrastructure projects. The changes prompted by technological innovation will have many positive effects for PPP infrastructure projects and the economy at large but will also present challenges. They open up new opportunities, but at the same time there are also new risks that need to be managed as emerging technologies radically change infrastructure planning, design, construction, service delivery, and management.

For illustrative purposes, below are: an overview of the main characteristics of PPPs that are relevant in the context of disruptive technology; examples of how disruptive innovation offers the opportunity to realize value across the PPP project life cycle; and some challenges disruptive technologies may bring about for PPP infrastructure projects.

[6] This is not a comprehensive overview but a selection of technologies that have already or will most likely disrupt infrastructure going forward.

[7] Appendixes B and C highlight trends related to the application of disruptive technologies in the energy and transport sector.

2.3.1. Disruptive Technology and PPPs

In a quickly changing technological environment, governments need to adopt new strategies that allow them to respond swiftly and adequately to unforeseen technological changes that may disrupt infrastructure. Because infrastructure assets are typically long-term investments, dealing with unforeseen technological advances is never easy, but some of the opportunities and challenges are particularly important in the context of infrastructure projects delivered through PPPs.

A PPP is defined as a way to procure, finance, develop and implement public infrastructure assets and services using the resources and expertise of the private sector. This includes developing new infrastructure (greenfield projects) and upgrading existing infrastructure (brownfield projects). Although there is no universally accepted definition of a PPP, in this report a PPP is referred to as "a long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance."

Because private enterprises are at the forefront of innovation, PPPs will likely remain relevant tools to improve the delivery of infrastructure services and to seize the potential offered by disruptive technologies, in particular in emerging markets. However, PPPs have their own complexities when it comes to the adoption of new technologies and dealing with a rapidly changing business environment—complexities that governments must recognize and be capable of addressing. Key differences—in comparison to infrastructure projects that are delivered by traditional procurement methods—that are relevant in this context are:

- PPP infrastructure projects are often long-term commitments, usually for a term of 20 to 30 years, and they require large capital investments. With disruptive technology on the rise, there is an increasing risk that assets cannot be used economically before the public or private investors have fully recovered their costs.
- PPPs involve complex contractual arrangements between several public and private sector counterparties, including third-party lenders and investors. Because PPPs are different from infrastructure projects that are entirely publicly funded and operated, governments cannot therefore unilaterally respond to unforeseen technological advances and counter the risk that the infrastructure asset becomes outdated—for example, by integrating digital technology in transport projects or by switching from fossil fuels to renewable energy.
- PPPs are based on careful risk analysis, commercial assumptions, and financial models that integrate service delivery cost considerations into the design phases of the projects, and that therefore make it more difficult to respond to unexpected disruptions. Under the PPP model, the private partner typically takes on the life-cycle management of the infrastructure. Obsolescence is a particularly heightened risk to private partners that have assumed revenue risk (e.g., tolling) based on financial models that were dependent on traffic forecasts.[8]

2.3.2. Which disruptive technology opportunities are relevant for PPP infrastructure projects?

The emerging technologies outlined in section 2.2 and Appendix A have the potential to integrate material, machine, and digital technologies across the infrastructure life cycle. Often referred to as InfraTech, they impact the development, delivery and ongoing operation of infrastructure, and create **new opportunities** for infrastructure service delivery that can benefit users, providers and societies alike.[9] Against this background,

[8] Pellen, Adrian. 2017. "Disruptive Technology Brings Risk and Opportunity to Infrastructure Projects." Marsh McLennan *BRINK*, August 14, 2017.

[9] *Stocktake of InfraTech Use Cases* by the Global Infrastructure Hub presents a collection of use cases demonstrating the application of InfraTech, with analysis of the sectors and technologies represented.

the InfraTech Agenda explicitly aims to accelerate the adoption of new technologies in infrastructure to support economic recovery and growth.[10]

New technologies are expected to increase **efficiencies** in the development, delivery and operation of assets; **reduce costs** for construction, and operation and maintenance; **extend the life of assets**; ensure greater **engagement of stakeholders** and users; and allow for the development of new models for infrastructure financing and asset optimization. The trend in disruptive innovation for all sectors is to enhance the **interconnection** of people and services around the world efficiently, reliably, and sustainably. These innovations are causing **value chains to be increasingly decentralized and globalized**.[11]

From a policy perspective, it is important to make a distinction between (i) technologies used in infrastructure design, planning, delivery and management versus (ii) the integration of technologies into the structures themselves, which changes the nature of infrastructure assets from simple inanimate objects to dynamic information systems.[12]

(a) Disruptive technology is changing the way we design, build, and manage infrastructure throughout the project cycle.
InfraTech applications can be adopted across the PPP project life cycle. These can include the following categories:

- **Development and planning:** The use of disruptive innovation—such as improved analytical functions, big data, artificial intelligence (AI), and the mobile internet—is already leading to material cost savings in the infrastructure preparation stage. It will likely also lead to faster and more informed decision-making because disruptive technology allows all team members to connect with real time visual data. One example where disruptive technology is already used for infrastructure development and planning is AI-enabled prediction and demand forecasting. Advanced analytics for planning also includes the use of complex city models with synthetic populations living in digital twins,[13] which are estimated to result in a 10 percent improvement in construction business effectiveness and more than 20 percent gains in productivity.[14]

- **Design:** Big data and improved analytics will influence how we design infrastructure. There has been an exponential increase in data sources helpful to the design process, including from satellite imagery, mobility records, social media, logistics, and transaction records. The cost of gathering data is also decreasing exponentially, with drones or crowd-sourcing techniques proving to be highly cost effective, and advanced analytical modeling techniques, such as **building information modeling (BIM)**, are already being used for 3D modeling in the design phase. Further innovations in technology will also provide insights into how a project will perform throughout its life cycle, allowing a view into a project's future risk profile.[15] In transport, for example, whole-of-system network models are used to rethink rail asset operations and renewals, allowing operators to manage operations risk and maintenance interdependencies more efficiently.[16]

[10] G20 Infrastructure Working Group. 2020. "G20 Riyadh InfraTech Agenda, Background."

[11] For more details, see the World Bank Group's 2020 *Infratech Policy Toolkit* and its 2020 *Infratech Value Drivers.*

[12] G20 Infrastructure Working Group. 2020. "G20 Riyadh InfraTech Agenda, Background."

[13] Digital twins integrate data, including real-time sensor data, to better visualize and optimize assets, ensure continuity of services, and make well-informed new investment decisions (Global Infrastructure Hub and G20 Infrastructure Working Group. 2020. *InfraTech Stock Take of Use Cases*. Reference Note, June 2020.).

[14] World Bank Group. 2020. *Infratech Value Drivers.*

[15] Pellen, Adrian. 2017. "Disruptive Technology Brings Risk and Opportunity to Infrastructure Projects." Marsh McLennan *BRINK*, August 14, 2017.

[16] World Bank Group. 2020. *Infratech Value Drivers.*

- **Procurement:** InfraTech is increasingly used in public procurement globally. Big data and data analytics can, for example, be used to optimize procurement. In order to prepare and analyze big data sets, AI and machine learning (ML) may be required. The incorporation of blockchain technology into the bidding and contracting process ensures transparency and reduces the risk for corruption related to the procurement of infrastructure projects, and also has the potential to reduce transaction costs.[17]
- **Construction:** Disruptive technology enables infrastructure to be built more efficiently: 3D printing technologies and new materials together with AI-enabled robots and construction equipment make it possible to lower the costs for construction and to minimize waste and human labor.[18] AI, ML, IoT, big data and improved analytics are already able to collect and aggregate a much larger flow of data than has been historically possible. These new technologies allow for real-time analysis of project progress, identify actionable realities, and communicate among project team members. **BIM** technology enables developers to create data-based, digital 3D models of projects so that architects, engineers, and contractors can simultaneously collaborate.[19] This innovation in BIM allows those who design infrastructure to provide real-time support to those building it.[20] Augmented reality and virtual reality help to create immersive experiences that provide insight into potential design flaws, risks, and issues before and during construction, and sending mini-robots into buildings under construction can also help track work as it progresses.
- **Maintenance:** Going forward, better use of big data and other disruptive technologies can help reduce the costs of maintenance and extend the life of the asset. Data from a variety of new sources, including satellite imagery, unmanned aerial vehicles (UAVs, or drones) will enable remote supervision of infrastructure assets. IoT technology and sensors can make maintenance more efficient by providing real-time data related to the condition of the infrastructure asset and its components, anticipating future maintenance and optimizing equipment performance. Real-time reporting and visualization via smartphones can turn large amounts of sensor data into usable intelligence to support complex asset decisions. Remote and automated methods (e.g., drones, IoT, robots) can maintain or increase the frequency of physical inspections to ensure critical infrastructure services are not interrupted and allow for targeted intervention. Further, AR and VR together with AI can aid technicians in making repairs in real-time.
- **Operation:** The availability of vast amounts of data through IoT on cloud-based platforms and the speed at which the data can be delivered can improve the efficiency, costs, and transparency related to the management of infrastructure. For example, with regard to parking management, disruptive innovation can allow operators to collect and distribute real-time information about where parking is available. Thus, they can assist drivers in finding open spaces quickly, and encourage them to park in underused areas and garages through demand-responsive pricing.[21] Moreover, new user interfaces and platforms driven by advanced technologies, including payment mechanisms together with drone/satellite-based surveying, have the potential to radically change customer experience. Due to the new possibilities created by InfraTech, some large transit agencies are starting to reduce costs (for operation and ticket prices) while increasing satisfaction and service levels by focusing on

[17] For more details, see the Deloitte 2020 *Study on Uptake of Emerging Technologies in Public Procurement.*

[18] World Bank Group. 2020. *Infratech Value Drivers.*

[19] A recent German highway project (Biebelried intersection and the Fürth/Erlangen intersection in the German state of Bavaria) uses, for example, cloud-based and fully integrated iTWO 4.0 technology based on 5D building information modelling (BIM) with AI integration. The use of cutting-edge technology allows stakeholders to upload and share vast quantities of data, including three-dimensional design applications, transparently and accurately throughout the entire project life cycle, thereby enabling faster and more efficient decision-making. WEF (World Economic Forum). 2021. *Why the world needs a fresh take on smart and sustainable infrastructure; Verfügbarkeitsmodell A3 AK Biebelried – AK Fürth/Erlangen, Nordbayern GmbH & Co. KG.* (Last visited September 13, 2022.)

[20] Pellen, Adrian. 2017. "Disruptive Technology Brings Risk and Opportunity to Infrastructure Projects." Marsh McLennan *BRINK*. August 14, 2017.

[21] SFPark Pilot Project. https://www.sfmta.com/projects/sfpark-pilot-program. (Last visited: September 13, 2022.)

self-service delivery and alternative business models.[22] Depending on the specific PPP infrastructure project, operation going forward may also be transformed by other InfraTech solutions, such as smart shipping containers that reduce the costs for lost or damaged cargo, battery improvements that allow renewable energy storage at off-peak hours, or AI-based deep-cleaning robots.

- **Management of PPP contracts:** Disruptive technologies can enable more collaborative and customer-centric projects. Blockchain and the different mechanisms it enables, such as smart contracts and the tokenization of infrastructure, may have the power to solve existing issues related to PPP projects that are derived from the lack of trust among parties, asymmetry of information, and lack of predictability and transparency. Collection and processing of real-time data through disruptive technologies can improve tracking and governance of projects.

(b) Disruptive innovation, such as robotics, AI, the internet of things, and other **technologies can also be integrated in physical infrastructure systems or used with existing technology**. This can make roads, urban transport systems, ports, wastewater treatment and power generation plants more efficient, more cost-effective, and more resilient towards outer shocks and stresses, and will change the way infrastructure is operated and used going forward.[23]

Examples:

- New electronics become available for **fiber optic projects** that make broadband internet traffic more efficient.
- **Road, bridge and tunnel projects** integrate **sensing technology for autonomous vehicles**.
- **Road projects** integrate new **intelligent transportation systems (ITS)** incorporating a variety of new technologies including Bluetooth, video, and other wireless systems to promote efficient traffic management, allow for toll tracking and billing, enhance emergency response times, and assist with law enforcement.
- **Urban transport** projects use trains that run on roads and rails, and use battery technology for electrification.
- **Smart cities** employ **ICT infrastructure**, namely high-speed wireless networks as well as other technologies, such as IoT and AI solutions, to manage and govern **municipal water and waste management, electricity generation, and street lighting**.

For additional examples, see Appendix A, which describes different disruptive technologies and how they are applied to infrastructure, and Appendixes B and C, which highlight trends related to disruptive innovation in the energy and transport sectors.

2.3.3. What are the challenges of disruptive technology for PPP infrastructure projects?

Alongside the benefits, the rapid change enabled by disruptive technologies is also bringing new uncertainties. New technology that makes decentralized distribution more attractive can lead to changes in demand on centralized energy projects; toll roads may require new traffic management technologies that lead to major efficiency gains but require high upfront costs; public transport schemes may become obsolete because of changes in technology that lead to advanced ride-sharing options. In addition, the exponential increase in data generated through new technologies such as AI and big data poses societal and technical challenges, including heightened cybersecurity risks and issues related to data privacy, protection, and confidentiality.[24]

[22] World Bank Group. 2020. *Infratech Value Drivers*.

[23] Examples of disruptive innovation that have occurred or are anticipated to occur specifically in the energy, transport, and information and communications technology sectors are explained in more detail in Appendix B.

[24] G20 Infrastructure Working Group. 2020. "G20 Riyadh InfraTech Agenda, Background." Risks and challenges of InfraTech are also described in more detail in *Infratech Value Drivers* (World Bank Group 2020).

Some of the key challenges of disruptive technology for PPP infrastructure projects include:

(a) **Technological obsolescence:** One major risk that comes with disruptive technology is that infrastructure that is designed or built today—or is already operational—will become outdated or inadequate for the purpose of the service, or will not fulfill technological standards set by the contracting authority or other government agencies in the future. Due to the rise of disruptive technologies, there is considerable uncertainty about which technologies and business models have the potential to become dominant and which sectors they will impact the most. For long-term PPP projects, this means that there is an increasingly high risk that key assumptions will have to be readjusted over the lifetime of a project. Although disruptive technology provides opportunities for investors, new technology standards or "green" requirements that are set off by fast-paced technological development put long-term investors under constant pressure to innovate and **upgrade infrastructure** or risk a **sharp decline in demand**.

A sharp **decline in demand** resulting from changes in key assumptions can result in either increased costs or lower revenues for the private partner or the contracting authorities, respectively. User-fee concessions (including roads, airports, ports, ferries, parking garages, etc.) could be facing stress due to reduced demand, whereas availability fee-based projects may come under pressure as the public sector faces fiscal limitations.

Eventually the PPP project could even become economically unviable—or so unattractive that it could be considered a **stranded asset**. For example, the displacement of landlines by mobile technology may make the operation of landlines economically unviable; in light of the climate targets from the Paris Agreement and falling prices for renewable energy projects, infrastructure projects that use fossil fuels, such as coal, have already become less attractive and may become stranded assets in the future.[25]

Examples:

- Price drops in the renewable energy market in recent years have made existing long-term power purchase agreements (PPAs) (even those with renewable energy) seem overly expensive and unattractive (see Box 1).
- Mobile technology displaces landlines, leaving investors of landlines stuck with obsolete infrastructure.
- Advances in battery storage technology lower demand for transmission networks.
- Increased digitalization reduces the need for commuting or business travel.
- Autonomous vehicles affect the way roads, refueling stations, and parking garages are used and supplant conventional vehicles, disrupting established infrastructure assets and supply chains.

[25] According to the International Energy Agency's (IEA) Renewable Energy Market Update "Challenges and opportunities beyond 2021" (last visited September 13, 2022), the cost of electricity from onshore wind and solar PV is increasingly cheaper than from new and some existing fossil fuel plants.

Box 1: The Rise of Renewables

PPPs in the energy sector are commonly structured as an arrangement with a single-purpose independent power producer (IPP) to design, own, operate, and maintain a power plant, and then sell the power generated by the plant to an offtaker, typically a government agency or government-owned utility, in accordance with a power purchase agreement (PPA). The PPA is typically for a period of 15 to 25 years and can provide a fixed feed-in tariff for the duration of the term.

With rapid advances in renewable energy technology, such as solar photovoltaic (PV) modules, prices for renewable energy power are falling, and existing long-term PPAs that are based on fixed tariffs are becoming increasingly unattractive. In addition, new procurement mechanisms—such as auctions—have proven effective in using competitive forces to bring down procurement prices, and market players that can give consumers economically attractive choices will likely disrupt centralized electricity production going forward. In such circumstances, many countries prefer to end existing, fixed-tariff contracts that were signed when solar and wind project development costs were higher.

Examples globally abound. A task force in Kenya, formed to address concerns about the high cost of electricity, recently presented its report and recommendations to Kenya's president. One of the recommendations is the review and renegotiation of existing power purchase agreements. Several states in India are trying to renegotiate renewable energy PPAs. In France a finance law enacted at the end of 2020 provides for the renegotiation of the feed-in tariffs of approximately 800 solar PPAs concluded between 2006 and 2010. Other examples can be found in the case studies in Section 5.

A variation of this risk is that disruptive technology leads to a situation where certain **equipment becomes inadequate** for the purpose of the service or is **required by new policies, legislation or standards**. The implementation and subsequent changes in operation may require some up-front cost and make the project more expensive than expected. If these new design elements were not foreseen when the PPP contract was closed, their implementation may also require **amendments to the performance indicators** or other PPP contractual provisions.

Examples:

- Technology may become available for fiber optic projects that do not fit exactly with project specifications but are more efficient.
- New technologies become common practice for high speed trains, requiring the operators of the high speed rail network to upgrade the entire system.
- Because autonomous vehicles rely to a large degree on sensing technology, existing roads, tunnels and bridges may need to be upgraded as more autonomous passenger vehicles and trucks enter the market.

(b) **Decentralization:** One general effect is that disruptive technology has a tendency to allow for more decentralization of infrastructure services. This decentralization makes it possible to **get around large-scale infrastructure providers and networks** and buy the services directly, thus decreasing demand for centralized infrastructure.

Examples:

- Availability of autonomous vehicles and ride sharing can decrease the demand for urban transport services.
- Decentralization in the energy sector. For example, rooftop solar systems with net meters not only allow consumers to generate their own electricity instead of buying it from the utility but actually enable the excess power to be fed back into the grid, thus decreasing demand for electricity produced by centralized power utilities and impacting their revenues and financial sustainability.

(c) **Cyber attacks:** Digitalization and data availability also increase the risk of cyber crimes. As infrastructure increasingly interconnects through the internet of things (IoT)—which enables services related to smart buildings, autonomous vehicles, and smart transit systems—cybersecurity risks become more of a threat for infrastructure than in the past. Large scale cyber attacks or the breakdown of critical information networks or systems can: impact the delivery or operation of infrastructure assets; interrupt relevant supply chains; and prevent potential infrastructure users from gaining access. Such attacks and breakdowns can thus lead to construction or infrastructure service delays or changes in demand.

(d) **Data theft:** With increased data exchange that is accessible for several parties, there is also a growing risk of massive data fraud or theft of private or official data. Personal or official data may be sold to third parties. Infrastructure can become a target for sophisticated organized crime organizations looking to extract sensitive information. Apart from the financial implications, projects may need to implement new legislation, policies, and regulations related data privacy during the course of the PPP project.

(e) **Economic and social disruption:** Some technologies also create broader economic and social risks as whole sectors are disrupted. Disruptive innovation could, for instance, lead to massive changes in the job market if human skills and talents are increasingly replaced with technology, or if new technologies replace old ones, requiring different skillsets or labor forces. Government policy or decisions to implement social standards to prevent adverse social effects of new technology (e.g., education and training for workers whose jobs could be made redundant) may also have cost implications for PPP projects in the long term. At the same time, it will be critical for industry to plan ahead by investing in education and training for these workers.[26]

Box 2: Coal Project Decommissioning and the Just Transition for All Framework

The World Bank has developed a Just Transition for All methodology that ensures that coal workers and communities are not lost within an energy transition and irreparably burdened with social and environmental legacy issues. This methodology, as narrowly applied to coal within the energy sector, (i) strengthens policies, regulations, institutional governance, and inclusive growth processes; (ii) ensures that workers and communities in coal regions are not left behind; (iii) properly closes coal mines and thermal power units to mitigate contributing further to public and climate risks; (iv) ensures adequate environmental remediation for repurposing of lands and infrastructure assets; and (v) strategically leverages public sector investments to attract private investors to sustain regional transformation.

Source: World Bank. "Just Transition for All: The World Bank Group's Support to Countries Transitioning Away from Coal." https://www.worldbank.org/en/topic/extractiveindustries/justtransition.

[26] Pellen, Adrian. 2017. "*Disruptive Technology Brings Risk and Opportunity to Infrastructure Projects,*" Marsh McLennan *BRINK*, August 14, 2017.

2.4. Disruptive Technology in the Context of Other Global Disruptions

The discussion of disruptive technology and its impacts on PPPs needs to be considered in the broader context of disruptions that have increased in recent years—and include unprecedented worldwide challenges such as climate change, natural disasters, economic disasters, and pandemics like the COVID-19 crisis. Although the nature of disruptive events and disruptive technologies differ, there are also similarities regarding single disruptive events in terms of impacts, scope, and approaches that may be applied to respond to them.

2.4.1. What Are Disruptive Events?

For the purpose of this report "disruptive events" are uncertain events or conditions—economic, climate, and health-related shocks—that have the potential to cause material damage to an infrastructure asset or to disrupt its operations. These types of events are often also referred to as **black swan events** (extremely unlikely and unforeseen events with very large impacts). Disruptive events include natural and man-made disasters (such as conflict and war), and economic and financial crises. These unforeseeable events have the potential to disrupt economies and to have a disastrous impact on certain infrastructure sectors. In particular the pandemic has highlighted some of the vulnerabilities and risks associated with unforeseen disruptive events on long-term PPP contracts.

Selection of disruptive events, plus examples:

- **Natural hazards:** Natural hazards are naturally occurring physical phenomena. They can be:
    - *Geophysical:* a hazard originating from solid earth (such as earthquakes, landslides and volcanic activity)
    - *Hydrological:* caused by the occurrence, movement and distribution of water on earth (such as floods and avalanches)
    - *Climatological:* relating to the climate (such as droughts and wildfires)
    - *Meteorological:* relating to weather conditions (such as cyclones, tornados and storms).
- **Man-made hazards:** Events that are caused by humans and occur in or close to human settlements. They include industrial accidents, transport accidents, environmental degradation and pollution, contamination, and technological failures. Examples of man-made disasters are the Chernobyl nuclear meltdown in Ukraine, the Deepwater Horizon oil spill in the Gulf of Mexico, and the Bhopal gas tragedy in India.
- **Economic hazards:** Economic hazards are sudden and severe events that upset parts of the economy. Examples are excessive debt burdens that generate sovereign debt crises and/or liquidity crises (fiscal crisis) or the failure of major financial mechanisms or institutions, i.e., the collapse of a financial institution and/or malfunctioning of a financial system that impacts the global economy. Other economic hazards that can impact infrastructure are severe energy price increases or decreases, or unmanageable inflation.[27] An example is the financial crisis of 2008, which disrupted the global economy and significantly affected many other sectors of the economy, including manufacturing, construction, and transportation.

[27] Marsh & McLennan. 2020. *2020 Global Risks for Infrastructure: Appendix*.

- **Biological hazards:** Biological hazards are a sub-group of natural hazards. They are caused by exposure to living organisms and their toxic substances or diseases they may carry (such as disease epidemics or pandemics; insect or animal plagues; parasites, bacteria and toxins). The transmission of biological hazards can cause great damage and loss of life, and can also lead to an economic crisis. A recent example is the COVID-19 pandemic that has interrupted global supply chains and caused economic and social disruption around the world.

- **Technological hazards:**[28] Technological hazards that qualify as disruptive events are large-scale cyber attacks or malware causing significant economic damage, or massive incidents of data fraud or theft. With the exponential pace of technological change, these risks have become increasingly significant for infrastructure. A breakdown of critical information infrastructure and networks (e.g., internet, satellites) causing widespread disruption would also qualify.

2.4.2. Comparison of disruptive events and disruptive technology

The rapidity of technological advancements in recent decades has increased the risk that disruptive changes will occur during the lifetime of a long-term PPP infrastructure project. The likeliness of both disruptive events and disruption caused by technological transformation has increased steadily in the last few decades, and both types have far-reaching consequences.

There are, however, clear differences between disruptive events and disruptive technologies in the context of infrastructure:

- The main difference is that disruptive events are usually viewed as negative events that should be avoided or mitigated (e.g., pandemics), whereas disruptive technology has the potential to transform infrastructure development and delivery, and to boost economic growth and private sector expansion. Disruptive technology is therefore generally viewed by governments and the private sector alike as progress that is incentivized and aspired to.

- Another key difference is that unlike disruptive events, which generally come on suddenly, the effects of disruptive technologies tend to manifest themselves over time.[29] Disruptive events can often be described as force majeure events, i.e., **external shocks** like earthquakes or wars, with **drastic consequences** that are beyond the control of both contractual parties and that make the performance of the contractual obligations of one party impossible.

- "Classic" disruptive events, such as floods or hurricanes, typically have **regional impacts** only, whereas technological disruption happens on a global scale.

- Unlike disruptive events, disruptive technology usually does not **damage the physical infrastructure**.

- **Adequate responses** to "classic" disruptive events are **contingency plans** and **emergency strategies**, whereas disruptive technology does not typically lead to an emergency situation.

[28] These risks are also discussed as a sub-group of man-made hazards.

[29] Although sometimes disruptive technologies may lead to a disruptive event—for example, strikes over a coal plant closure triggered by renewable energy technology can potentially lead to an economic crisis.

Despite these differences there are, however, characteristics disruptive technologies share with specific disruptive events:

- In parallel to the challenges brought about by COVID-19, climate change, and economic disruptions, large-scale technological transitions **create winners and losers**. Technological change is at once a constant threat for one sector or project type, e.g., fossil fuel projects, and an opportunity for another, e.g., the renewable energy sector. Similarly, digitalization spurred by COVID-19 measures led to rapid growth in digital platform-based infrastructure services, such as online education or online health care services, while the demand for public transport was declining.
- Similar to some disruptive events, risks associated with disruptive technologies fall into two categories: On the one hand, they can **trigger acute shocks** that are difficult to foresee (e.g., black swan events like cyber attacks or natural disasters caused by extreme weather events). On the other hand, some causes of disruptive events, such as climate change or a deteriorating global economic environment that leads to a financial crisis, can **build up gradually and cause "chronic stresses"** that lead to long-term changes that are to some extent predictable.
- More and more disruptions—whether they are caused by external shocks and stresses or through technological advances—have not only a regional but also a **global impact**.
- Several typical **consequences** of disruptive events can also be viewed with regard to disruptive technologies. Though disruptive technologies do not usually cause physical damage to infrastructure assets, disruptive events and disruptive technologies alike can have severe long-term consequences that can be similar, including social unrest and disruptions in supply chains, demand, and economic activity.
- **Actions that need to be taken to mitigate, prepare for, or prevent** disruptive events go beyond emergency measures and contingency plans and include, for example, long-term climate change mitigation and adaptation measures, which may then themselves have the ability to transform infrastructure sectors over time.
- It is **difficult to predict** the occurrence as well as the impacts caused by disruptive events and disruptive technologies. Due to these uncertainties, risks associated with both types of disruptions cannot be fully assessed and allocated to the parties in a PPP contract. These risks are therefore typically not sufficiently reflected in the PPP contractual terms.
- Disruptive events and disruptive technology alike can **change the contractual equilibrium** during the term of a PPP infrastructure contract up to the point where an asset becomes useless (stranded asset).

2.4.3. Can lessons regarding disruptive events be applied to disruptive technology?

The growing number and intensity of disruptions caused by black swan events and their far-reaching consequences have started an ongoing discussion on how PPP frameworks can be strengthened to ensure that the causes for disastrous events are mitigated, and future projects are made more resilient to these shocks and stresses. Consequently, during the past decade case studies, in-depth analyses, and tools that deal with uncertainty in the framework of PPPs have been developed. In addition, consideration has gone into how to address these challenges through proper risk allocation, contractual predictability and flexibility.[30]

Though the nature of disruptive events and disruptive technologies differs, useful guidance can be drawn from the global experience of the impact of disruptive events on PPPs; analysis of underlying issues, occurrence and impacts of risks and ways to address them; and tools that have been developed to deal with the growing number of disruptive events in the context of PPPs. The lessons learned and approaches discussed or taken with regard to specific disruptive events can therefore provide a useful basis for the development of guidelines aiming to enhance the resilience of PPP contracts and contract management in the context of the exponential pace of technology change. This report is therefore embedded in the broader discussion of disruptive events.

[30] See, for example *The Climate Toolkits for Infrastructure PPPs* (World Bank 2022). Links to other relevant resources related to PPPs, climate change and natural disasters are accessible through Climate-Smart PPPs: Further Reading and Resources on the PPPLRC website. For detailed resources related to pandemics and epidemics and PPPs, see Covid-19 & PPPs on the PPPLRC website. Regarding financial crisis and PPPs, see *The Effects of the Financial Crisis on Public-Private Partnerships* (P. Burger, J. Tyson, I. Karpowicz, and M. Delgado Coelho, IMF 2009).

3

Enhancing "Innovation Resilience" and the Adoption of Disruptive Technology throughout the PPP Project Cycle

3. Enhancing "Innovation Resilience" and the Adoption of Disruptive Technology throughout the PPP Project Cycle

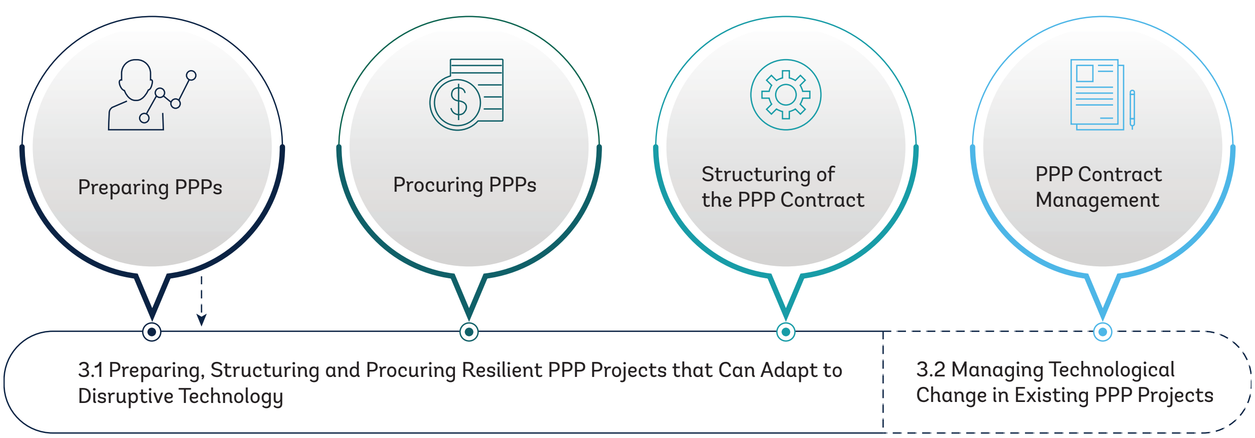
We are living in a world of transformative changes. Technological advances together with the transition to a carbon-free future revolutionize the way we live and interact with the world and could have immense implications for infrastructure PPPs. To reap the benefits of technological advances, PPP infrastructure projects must be planned and designed with a view to potential upsides to such advances while maintaining the flexibility to adapt to unforeseen downsides or risks.

This section will discuss what governments need to consider during the different development stages of PPP projects, including the procurement, structuring, and drafting of PPP contracts. The section will also address the management of existing PPP contracts if the reader wants to facilitate the adoption of innovative technologies and respond effectively to the challenges of technological disruption.

The first part of this section discusses how "innovation resilience" and the adoption of emerging technologies can be enhanced throughout the project development stage going forward. It also gives a brief overview of some best-practice approaches that can be considered during the project preparation stage, including the structuring and procurement of PPP contracts. The aim of this section is to give the reader a basic understanding of the proactive steps that can be taken during the project development phase to anticipate potential changes and identify measures necessary to deal with expected changes while adding sufficient flexibility so that PPPs can respond efficiently and effectively to the opportunities and risks of this new technological era.

The second part of this section focuses on existing PPP projects and addresses disruptive technology from a contract management perspective. It outlines typical adjustment mechanisms that are encountered in most PPP contracts or legal systems governing PPP contracts, including the key underlying economic principles that may allow the parties to manage circumstances that were not fully envisaged at financial closure. In addition, it discusses mechanisms that are important tools for the management of unexpected changes, such as renegotiation frameworks, dispute resolution systems, and termination regimes. The aim of this section is to describe what governments have to consider with regard to projects that are already implemented in a changing technological environment, and to highlight emerging best practices that can inform future PPP contracts and contract management.

3.1. Preparing, Structuring and Procuring Resilient PPP Projects that Can Adapt to Disruptive Technology

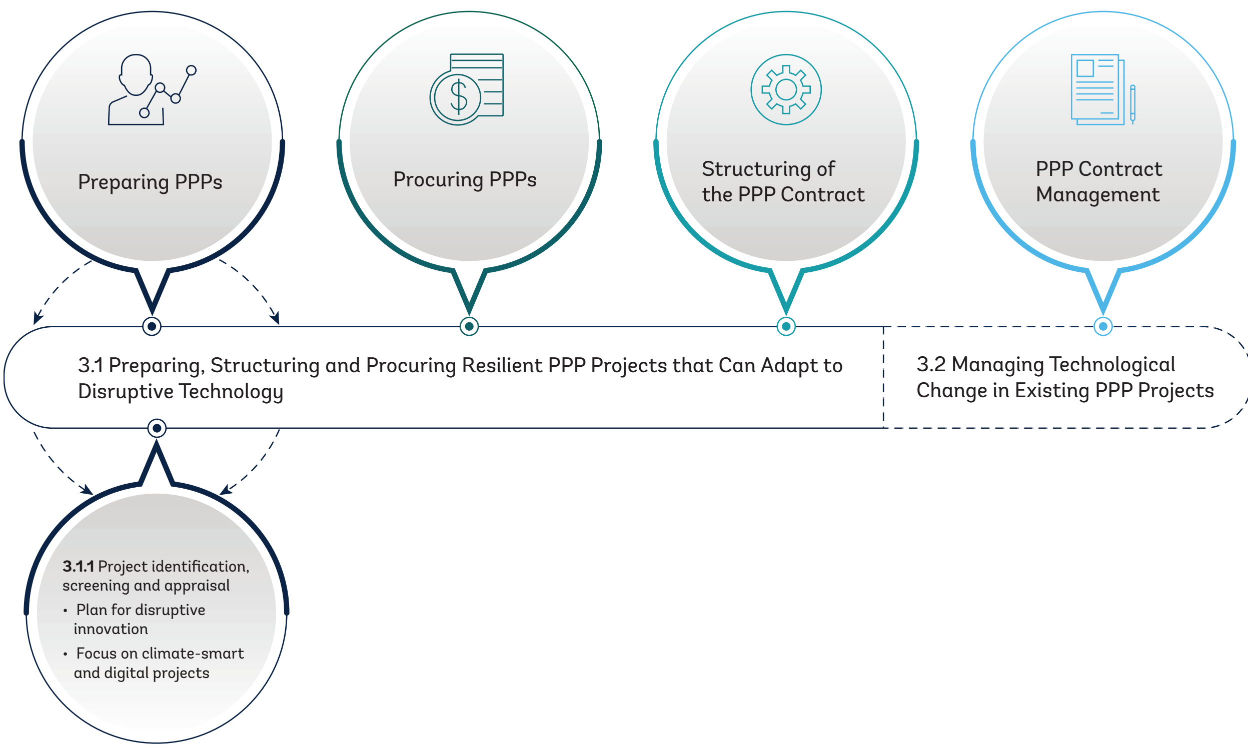


The adoption and application of technology-enabled infrastructure as well as "innovation resilience" of PPP projects needs to be considered in the broader context of PPP project preparation and delivery against the background of the G20 Principles for Quality Infrastructure Investment.

These principles acknowledge that disruption and change have become the norm, and they stress that advanced technologies are an important component for new and existing assets. Two important ingredients of quality infrastructure are therefore (i) that it is resilient to natural disasters and other human-made risks,[31] i.e., planned, designed, built, and operated in a way that anticipates, prepares for, and adapts to changing circumstances and can withstand, respond to and recover swiftly from potential disruptions; and (ii) that it leverages innovative technologies through its life cycle to raise economic efficiency for existing and new infrastructure.[32]

Complex PPP infrastructure projects thus require new strategies that integrate InfraTech into the planning, design, procurement, and contracting stages and at the same time reflect the uncertainty and broad range of disruptive technology risks these projects may encounter over their life cycles. This section highlights key considerations regarding mechanisms that could be applied starting from an early stage of project preparation that could shape and determine the drafting of individual PPP contracts in times of rapid technological advancement going forward.

3.1.1. Project identification, screening and appraisal



Both governments and investors must consider longer-term planning in the project identification, screening and appraisal process, to ensure the sustainability of projects built today that will still be relevant in a world many years in the future.

[31] Principle 4: "Building Resilience against Natural Disasters and Other Risks," *G20 Principles for Quality Infrastructure Investment*. This principle has been developed for disruptive events but it can also be applied to some extent to disruptive technologies. Disruptions such as the rising rates and intensity of climate change-related natural and other disasters, the 2008 financial crisis, the 2022 Ukraine-Russia conflict and the dramatic impact of the COVID-19 pandemic on infrastructure have shown the importance of quality infrastructure development to prevent and counter disruption.

[32] Principle 2: "Raising Economic Efficiency in View of Life-Cycle Cost," *G20 Principles for Quality Infrastructure Investment.*

During the **project identification** stage, governments identify potential projects and screen the priority projects in order to determine whether they have the potential to generate value for money (VfM) if they are implemented as PPPsGiven that PPP contracts are usually for a period of 15 to 35 years, it is important for both the government and the developer during this stage to look forward and consider if trends in technological development may impact their projects decades hence.

For example, many governments increasingly want to prioritize digital and "green" infrastructure projects in these times of technological transformation and ambitious worldwide goals to cut carbon emissions. Thus, long-term investments in carbon-intensive sectors may become less attractive for governments and investors. Similarly, when planning urban projects, governments and investors may wish to consider trends towards smart and livable cities, with younger generations embracing denser urban centers with green spaces, cycling lanes, and public transport.

Box 3: Importance of Assessments that Account for Technological Changes: European Stranded Assets in the Utility Sector, 2010–2015

The development of the European utility industry since 2010 offers valuable lessons about how quickly and dramatically seemingly stable industries can change, and what implications this can have for investors. In 2005 the utility sector in Europe was highly profitable. In most integrated power utilities, the generation business represented a majority of earnings, the power plants were seen as the core assets of the company, and mergers and acquisitions resulted in large players that forecasted a steadily growing demand—based on the assumption that 1 percent gross domestic product (GDP) growth would result in an increased electricity demand of 0.5 percent to 0.8 percent. The reality looked different.

For the large utility players in Europe, a combination of falling energy prices, a push for renewable energy, advances in renewable power technology, energy efficiency improvements, and an economy that was weakened by the economic crisis in 2008 and 2009 created a toxic mix of negative growth, low utilization of large-scale power plants, and substantial margin pressure. Total impairment for the 10 largest power utilities was €129 billion from 2010 through 2015, and accelerated at a rate of 24 percent per annum. Of these 10 power utilities, six have seen a share price drop of more than 55 percent, from 2010 to 2016. If this development had been predicted at least partly just a few years earlier, construction of new fossil plants would have been stopped earlier, and enormous value would have been saved. It is sometimes argued that this was not a black swan event, and that a large part of what happened was actually predictable. Although the financial crisis and the decrease in coal and CO2 prices was difficult to foresee, the policy makers' push towards decarbonization and renewable power was largely predictable, and the changing electricity/GDP growth ratio should also have been foreseeable.

Source: SEI (Stockholm Environmental Institute) and Material Economics. 2018. *Framing Stranded Asset Risks in an Age of Disruption.*

Regulatory Asset-Based Approach (RAB) - Does a RAB provide a better protection against asset stranding in comparison to the PPP model?

As mentioned above, one concern related to long-term PPP arrangements is that they may not be flexible enough to deal with unforeseen technological changes, in particular if they trigger structural changes in the market and asset stranding. Another model for private sector financing of infrastructure that has emerged and is sometimes discussed in this context is the Regulatory Asset-Based Approach (RAB).

For many years, many regulated companies, such as utilities, have used this approach. Under the generic RAB approach, the regulated company owns, invests in, and operates the infrastructure asset. It receives revenue from users and/or subsidies to fund its operations and recoup the investment costs. An economic regulator sets the tariffs to be charged by the regulated company to end users of the infrastructure. In order to identify an appropriate tariff, the economic regulator monitors both the company's operating costs and the capital investments which it makes in respect of the infrastructure asset. The regulator then includes, in the tariff, an amount to cover the allowed operating and maintenance costs, plus financing cost of the capital investments (the cost of equity and debt, including an allowed return). Tariffs are reviewed and adjusted periodically by the regulator. Regulators have developed different models and introduced performance-based frameworks that encourage innovation between reviews (see also Box 7: United Kingdom: Office of Gas and Electricity Markets (Ofgem)—Framework for Price Control Incentivizes Innovation).

In the context of disruptive technology the RAB model has in particular advantages regarding the renegotiation of tariffs versus the PPP mode. The RAB model in the framework of price cap regulation represents a regulatory contract in the form of a license -- with a string of renegotiations, I.e. price reviews. These allow adjustments to the changing environment without weakening the ex-ante commitment of the bidders or influencing the future expectations of investors. Renegotiations of a PPP contract are invariably less structured than in a RAB model, primarily, because there is no economic regulator in the background.

However, while the RAB approach has been successful with regard to utilities it has also drawbacks that are explained in more detail in the sources listed below. One of the disadvantages is that the asset base of a regulated utility contains a collection of assets, with the result being that the individual assets are not subject to the same cost discipline as would apply to a PPP project. In addition, the effectiveness of the RAB depends on the quality of the regulator who needs to have the capacity and experience to control and monitor a number of infrastructure assets in order to set the right tariff, which may sometimes lack in developing countries.

Sources:

The Regulatory Asset Base Model and the Project Finance Model: A comparative analysis, International Transport Forum 2015.
Resetting price controls for privatized utilities : a manual for regulators. Economic Development Institute of the World Bank, 1999.
Restoring Confidence in Public–Private Partnerships - Reforming Risk Allocation and Creating More Collaborative PPPs, ADB 2020.

Once the government has identified priority projects, the potential project will be **appraised** as part of a detailed business plan. After the high-level assessment during the screening phase, the project will undergo an in-depth analysis of its feasibility, risks, and potential mitigation measures, including the project's value for money and its fiscal implications during the appraisal stage. Unlike disruptive events, which can be enumerated (such as in force majeure clauses), predicting future technology development and how it will shape infrastructure is almost impossible. However, governments should, for example, carefully identify the types of risks that need to be considered as part of project design and those that could jeopardize implementation and assess the potential use of InfraTech in the project's feasibility study.

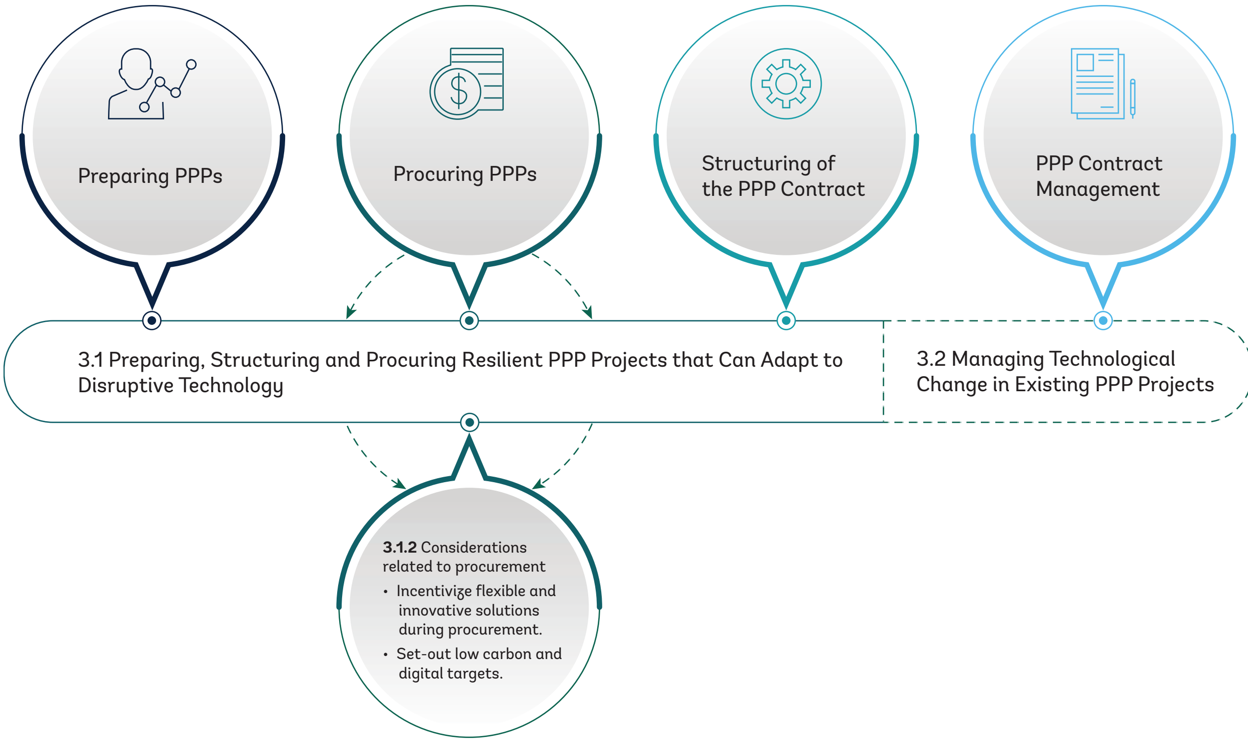
Indeed, future disruptive technologies are not necessarily black swan events. Though the exact impact of disruptive technologies may be difficult to predict, certain flexibility can be factored in when PPPs are prepared, with an understanding that disruptions and innovations in technologies, business, and policy can change the expected outcome of a project. Therefore, risks that are associated with potential technological changes need to be identified and assessed at this stage, including strategies that could mitigate these risks, whereas remaining risks need to be allocated carefully to the respective parties. At the same time, rapid technological changes make it necessary to assess how new technologies can be integrated into projects throughout all stages, and to find mechanisms to incentivize and facilitate innovation.

The **additional risk of obsolescence** means that governments and investors need the **capacity and expertise** to determine technology trends in specific sectors, and to assess whether essential technology will likely change during the term of the PPP contract, making the infrastructure asset obsolete. In particular, technical developments that may lead to stranded assets need to be factored into the respective methodologies and risk assessments, including financial models. This is especially relevant for projects that are most affected by an accelerated shift towards low carbon technology.

In addition, increasing digitization and use of disruptive technology in PPP infrastructure projects could make it necessary to use mechanisms similar to environmental and social impact assessments (ESIAs) going forward, to identify and assess potential adverse effects of disruptive technology on communities and the larger society as well as potential benefits. This includes the assessment of risks related to **extensive data collection and surveillance** as well as **data privacy issues**. If the use of disruptive technology includes the collection of private data, governments should ensure that they understand what entities collect, use, and own the data, and how the data can be protected after the project has been terminated. This topic cannot be covered extensively within the scope of this report. Guidance is needed in this regard, in particular if disruptive technology is implemented through PPPs in countries where regulation may be missing or where regulatory frameworks have gaps. Against this background, the International Finance Corporation (IFC) has recently developed a code of conduct relating to the management of risks arising from the adoption of disruptive technologies.[33]

[33] Myers, Gordon, and Kiril Nejkov. 2020. *Developing Artificial Intelligence Sustainably: Toward a Practical Code of Conduct for Disruptive Technologies*; IFC (International Finance Corporation). 2020. *IFC Technology Code of Conduct— Progression Matrix*. Public Draft.

3.1.2. Considerations related to procurement



Procurement of infrastructure PPPs typically provides limited flexibility to modify the project if the external conditions change after delivery (see Section 4.2 for details). For example, the pricing scheme of an energy project cannot simply be adjusted if the forecasted demand changes after the project has been implemented. In order to achieve more flexibility, a view across the entire life cycle of the project is helpful for the procurement of PPP projects.

This means as a first step that the various assessments undertaken during the project preparation stage, that did consider potential developments related to disruptive technologies, should inform the **tender requirements** specified by the contracting authority, as well as the terms of the PPP contract. If a project takes place in a sector where a high risk for technological change and obsolescence has been identified—due to fast-paced technological changes in a specific sector or in relation to a specific asset type or technology envisaged—governments may want to develop and use new procurement approaches. The aim of these models is to move away from the use of lowest-cost procurement, which often does not take into account the use of the best technology and the costs associated with effectively implementing these projects.[34]

Innovative solutions can, for example, be encouraged through approaches that set out low-carbon or digital targets; focus on VfM and life-cycle costs; introduce **collaborative procurement methods,** including contracting approaches for procurement that allow bidders to prepare alternative proposals; or separate technical and pricing aspects of bids.[35]

[34] World Bank Group. 2020. *Infratech Policy Toolkit*.

[35] World Bank Group. 2020. *Infratech Value Drivers.*

Box 4: Encouraging Innovation through Procurement: Alternative Technical Concepts (ATCs) in the United States

The use of ATCs has become a standard practice for design-build and PPP transportation projects in the United States. The practice allows bidders to modify technical requirements by allowing proposers to confidentially propose innovations and technical enhancements that would not otherwise comply with the request for proposal (RFP) requirements in a pre-proposal ATC process. If the contracting authority approves a proposer's ATC, the proposer has the right to submit a proposal that incorporates the approved deviation from the technical requirements without concern that its proposal will be rejected as non-conforming. ATCs encourage innovation by obtaining competitive pricing for innovation and reducing the risk of outdated design.

Source: US Department of Transportation. 2019. *Public-Private Partnership (P3) Procurement: A Guide for Public Owners.*

See also "Case Study 5: United States, Maryland — The I-495 & I-270 PPP Highway Project." This project used an innovative dialogue process to incentivize innovation beyond the wording of the RFP requirements and a comprehensive public engagement process.

Where a high risk of stranded assets has been identified, the tender can be designed in a way that the quality of the technical solution and its flexibility to adapt to a changing technological landscape is considered. This may require a separation of the technical and pricing aspects of bids.

Box 5: Broadband PPP Project in Meurthe-et-Moselle, France: Importance of Award Criteria in the Face of Rapid Technological Change

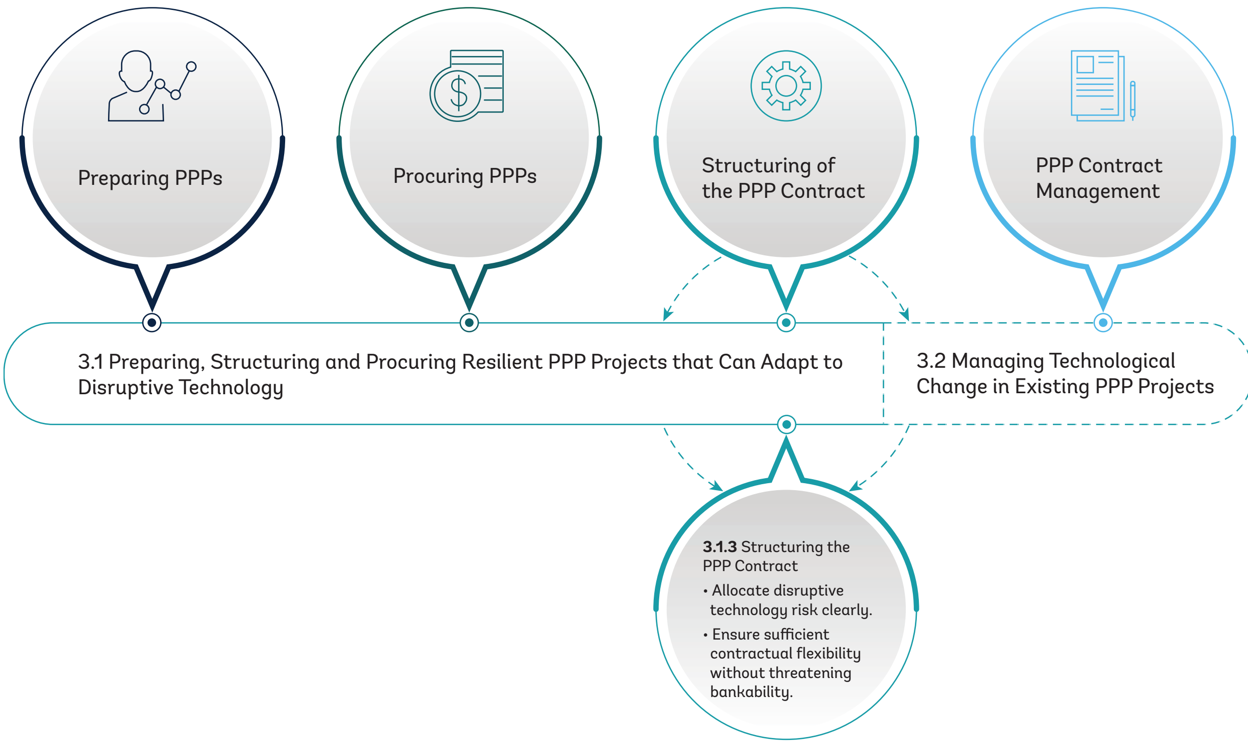
The award criteria for the broadband project in Meurthe-et-Moselle emphasized the speed factor in achieving the desired geographical coverage, but no points were awarded for the quality of the technical solutions proposed by the tenderers.

Consequently, although 95 percent of the households have been covered at six megabits per second (Mbps), in many cases this comes through satellite or Wi-Fi-MAX, less durable and less high-performing technologies that are not in line with the tendency to expand the coverage of households with fiber optic. Considerable additional resources have therefore had to be set aside in order to update network quality on a regular basis, so that the cost of major infrastructure maintenance and renewal (€32 million) accounts for 84.4 percent of the total project investment cost of €37 million—a considerably higher proportion than in other broadband projects which use fiber optics more intensively.

Source: European Court of Auditors. 2018. *Public Private Partnerships in the EU: Widespread shortcomings and limited benefits.*

It is strongly recommended that competitive procurement methods are used to select the investor whenever feasible,[36] including through innovative methods of price competition, such as auctions.[37] However, a direct contracting model may sometimes work better for the development of innovative solutions in less mature PPP markets—if market interest is low and local capacity may not be sufficient to procure and deliver complex PPP projects. More generally, governments might benefit from building a process that allows them to receive unsolicited proposals because this can help ensure that the use of innovative technology is not inadvertently prevented by a rigid procurement structure.[38] More generally, the introduction of outcome-based procurement frameworks that align the objectives of both the planning authorities and the private sector organizations and ensure the achievement of other benefits envisaged by the public sector, such as delivery of environmental and social impacts, may be beneficial to encourage the adoption of InfraTech.[39]

3.1.3. Structuring the PPP contract: addressing risks and opportunities related to technological innovation



Long-term, complex PPP projects always have to deal with unpredicted changes. Traffic volumes may turn out to be lower or higher than the predicted demand for a tolled highway project; efficiency-enhancing technology may become available for a water treatment plant; network assets may last more or less time than assumed. PPP contracts are therefore necessarily incomplete; they need flexibility to be built in—flexibility that allows unexpected circumstances to be accommodated within the contract, thus reducing the chance of disputes, lengthy renegotiations, and early termination. Such adjustment mechanisms create processes and boundaries for change.

[36] For unsolicited proposals (USPs), it is recommended that the project is still in some way open for other parties to compete. For details, see the World Bank Group and PPIAF's *Policy Guidelines for Managing Unsolicited Proposals*, Volumes I–III.

[37] Solar auctions, for example, have been very successful at achieving record-breaking low PPA prices for the government (to the point where it must also be considered whether such prices are sustainable in the longer term, given the low margins being accepted by developers). Nonetheless, it has been shown that competitive methods are effective at bringing value for money for the contracting authority.

[38] World Bank Group. 2020. *Infratech Policy Toolkit*.

[39] Promoting InfraTech adoption across the Infrastructure lifecycle, PwC and Global Infrastructure Facility (GIF) 2021.

The fast pace of recent technological progress and its dynamic and global impact make PPP contracts, however, more vulnerable to unpredictable change than ever before.[40] In this changing environment, the ability to adapt quickly to disruptive technology can make the difference between the success of a project and its failure. More contractual flexibility can be ensured prior to signing through proper contract drafting that takes technological disruption, and the possibility that economic conditions change after the PPP contract has been signed, into account. This may require a customization of the risk allocation to the distinctive characteristics of a project and drafting of bespoke PPP contractual provisions. These have to provide enough flexibility to permit a swift response to technological progress without threatening the bankability and affordability of projects. To achieve this goal, a clear allocation of disruptive technology risks is important—keeping in mind that the private partner will likely charge a risk premium if it has to assume disruptive technology risks that cannot be properly priced or assessed. Ultimately, a balanced and reasonable risk allocation requires that all stakeholders in a PPP project have the comfort that situations that are beyond their immediate control and that affect contractual performance will be dealt with in a way that allows them to arrive at a mutually acceptable solution.[41]

This section outlines basic considerations related to risk allocation in the face of rapid technological progress. The applicability and scope of typical adjustment mechanisms together with guidance for future PPP contracts is discussed in more detail Section 4.2.

(a) **Risk allocation** The first step toward structuring a PPP is often to put together a list of all the risks associated with the project. After the project risks have been identified and analyzed, they need to be allocated between the contracting authority and the private partner and translated into legal obligations in the draft PPP contract. The underlying principle is that the risks associated with carrying out a PPP project are allocated to the party best able to control or to manage the consequences of the risk.

Considerations for a balanced allocation of risks related to disruptive innovation:

- The demand of an infrastructure service typically depends on developments that are outside the control of the private partner. Consequently, the allocation of the **demand risk** (or revenue risk) is driven by the specific circumstances of the project, in particular whether and how much the private partner can influence the demand, e.g., by improving service or through marketing campaigns. Whether the contracting authority bears the **demand risk** (or revenue risk) or has transferred it (partially) to the private partner is reflected in the specific PPP payment model.

[40] Disruptive technologies and their impacts on infrastructure, including risks and opportunities for infrastructure PPPs, are described in more detail in sections 3.2 and 3.3.

[41] For further details on risk allocation, see the World Bank Group's 2019 *Guidance on PPP Contractual Provisions*, PPP Contracts in Context, K.

Demand Risk: PPP Payment Models

There are different PPP payment models that vary depending on the allocation of the demand risk. The potential consequences of changes in demand therefore depend on the PPP payment model. The basic PPP payment models are:

User-pays model (user pay contracts): In this payment model, the private partner generates revenue by charging end-user fees, tariffs or tolls. Under this approach, the private partner and its lenders bear the demand risk, i.e., lower number of users or usage volume than anticipated. A lower demand than what was forecasted thus reduces the revenue of the private partner. Typical examples are PPP road projects where tolls are collected directly by the private partner.

Government-pays model (availability-based contracts): In this model, the private partner receives regular payments from the contracting authority if the infrastructure asset or its services are available at a contractually defined quality regardless of the level of use. In these cases, the contracting authority retains the demand risk, and the total revenue of the private partner does not change if demand decreases. The government revenue can be higher or lower than the payments made to the private partner—which can have severe long-term fiscal and budgetary implications. Government-pays models are common for PPP projects that do not have a steady revenue stream, or projects where the government prefers to take the demand risk, e.g., for policy reasons. Typical examples are PPPs in social sectors, such as schools or prisons, or toll road concessions where the government assumes all traffic risk.

Minimum revenue guarantees (take-or-pay clauses): Minimum revenue guarantees are user paid, but if there is a shortfall below a certain threshold, the contracting authority will make up such a shortfall. Thus demand risk is passed largely to the contracting authority. Minimum revenue guarantees are often found in urban transport projects, for example. A similar concept exists in energy sector power purchase agreements, which often contain a take or pay clause that obliges the offtaker or utility to take a minimum amount of electricity or pay for any shortfall. This clause provides the project owner with a guaranteed offtake, but it can become burdensome for public utilities if it ends up paying for more electricity than it needs. This issue is exacerbated in the case of technological change; for example, when governments are being pressured to meet climate goals and renewable energy targets but are currently still under contract for paying for a certain amount of electricity generated by coal power, limiting their ability to pivot to building new renewable energy plants. In some instances, utilities simply cannot afford the capacity payments under PPAs that they have signed, and are thus subjecting the project owners to curtailment of electricity. Future contracts should consider building in flexibility for take-or-pay clauses in specific circumstances. Often, there are moratoriums on such payments in the case of force majeure. Such contracts can possibly also consider allowing the project owner to find other ways of offloading their electricity (i.e., liberalizing the market) so that the burden of meeting demand does not reside with the utility.

- It is difficult to allocate the **risk of technological obsolescence** expressly in PPP contracts. The allocation of the risk that new technology displaces the underlying technology of an infrastructure asset, or that equipment and material becomes obsolete, will depend on the specific circumstances. Factors that are relevant for an appropriate risk allocation are: the likelihood of the technological change in the sector and for the specific project type; possibilities to upgrade the asset to prevent it from becoming obsolete or useless; the costs that may be involved in such upgrades; and the ability of either party to bear the impact of the change and whether or not it can be passed on (e.g., to the end user or tax payers).
- As a general rule, the **risk that innovative technology becomes available** has to be assumed by the private partner, which will usually have an incentive to implement changes in technology that become market standard in particular if they reduce long-term costs. A requirement to implement technological

enhancements is often described in the PPP contract. These contractual mechanisms are outlined in more detail below. However, in the cases where the implementation of new technologies comes with high upfront costs or recurring costs that could not be foreseen by the parties when they entered into the contract and threatens to disturb the economic balance, a shared risk approach together with a benefit sharing mechanism could be more suitable to achieve a balanced and reasonable risk allocation.

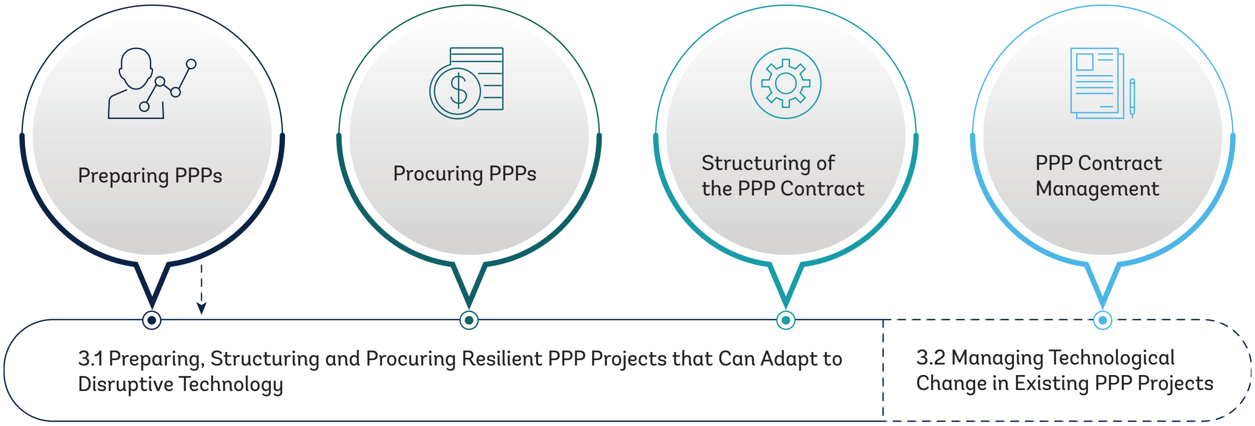
- A subset of the risk of technological obsolescence is the **risk that disruptive technology changes the circumstances outside the PPP project** and makes the project significantly more expensive in comparison with another project (e.g., feed-in tariffs the parties agreed to are not competitive anymore) or changes the demand for a specific infrastructure service drastically (e.g., fossil fuel loses attractiveness as renewable energy technology advances). If the risk of technological obsolescence is under specific circumstances outside both parties' control and neither is better placed than the other to manage the risk or its consequences, it may be most appropriate to treat it as a shared risk.
- In the context of increasing global digitization and connectivity, **cyber intrusion and cyber risks** have become a challenge for infrastructure projects. When it comes to cyber risk, it is difficult to identify one party to which the risk can be allocated. Details will depend on the potential loss that could occur in the event of a cyber incident as well as the level of risk mitigation that can be expected by each party and to what extent the parties can take out insurance.

(b) **Enhancing flexibility** It is impossible to assess all possibilities and allocate all potential risks correctly over a long period of time in large projects that take place in regulated sectors, diverse political settings, and at times of increasingly complex and interconnected technology. Therefore PPP contracts need to have some flexibility built in that allows the parties to incorporate new technologies, find solutions to share high upfront costs, and gain sharing mechanisms, all while managing unforeseen circumstances within the contract to avoid disputes, renegotiation, and termination as much as possible.

Flexibility that allows projects to keep pace with innovation can be found to some extent in basic provisions that take a degree of technological change into account. These are the first provisions that should be strengthened in future contracts in order to ensure sufficient flexibility in dealing with technological change. Moreover, PPP contracts incorporate a set of typical provisions to deal with unexpected change and allocate associated risks to the parties. These provisions need to be reviewed in light of rapid technological change.

Ultimately, however, a long-term PPP contract will be limited in how much flexibility can be introduced without threatening its bankability. PPP projects are by nature dependent on a set financial model at the outset to raise financing for the upfront construction costs. Once that financing is committed, it is very difficult to adjust any variables or assumptions in the model, and attempts to do so almost inevitably result in renegotiation or disputes.

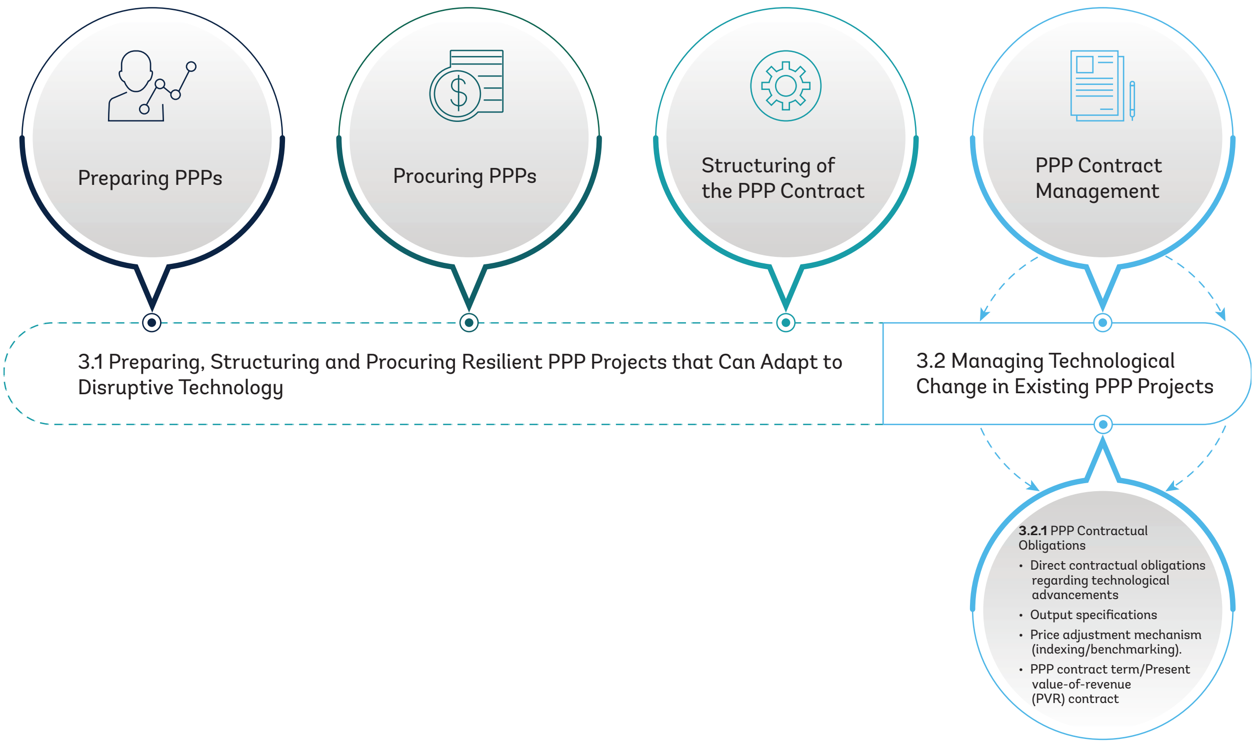
3.2. Managing Technological Change in Existing PPP Projects



This section discusses how existing PPP projects can manage technological change that may occur during the project implementation phase.[42] This includes the management of changes that are permitted in the PPP contract or by the law that governs the contract, such as output specifications; periodic changes in the scope of work or tariffs; and unforeseen changes caused by external events or changes in law. Against the background of the transformative nature of some technological changes that are underway and have the potential to reshape entire infrastructure sectors, it is natural to expect that the parties will at some point during the contract term face circumstances that cannot be dealt with by the adjustment mechanisms provided for in the PPP contract. These changes in circumstance may need to be addressed through renegotiation frameworks as well as the dispute resolution processes and termination regimes set out in the respective PPP contracts or legal systems governing the contract.

[42] The administrative arrangements and processes for handling change are often further defined as part of the contract management framework and materials. Although rules and processes for change are usually specified in the PPP contract, room for discretion is likely to remain.

3.2.1. Contractual obligations to adjust the project to a changing technological environment



(i) Output specifications

One of the key benefits of a PPP is that it gives contracting authorities the increased opportunity to take advantage of private sector expertise. That is why the best practice in regard to a PPP transaction is for the government to use output specifications that leave it to the private sector party to be innovative in responding to these requirements and to adopt, for example, innovative technologies.

Although most types of technological innovation that either the private partner or the contracting authority wishes to introduce have to be agreed upon by the parties, others may be specified as desired output specifications. The private partner's obligation is to meet these output specifications. If the private partner is required to integrate specific advancements in technology and fails to do so, it is likely to suffer payment deductions and, above a particular threshold, may be at risk of termination. However, if it complies with the output specifications, the contracting authority cannot simply require it to replace technology because more efficient technological solutions are available unless there is an agreed contractual mechanism for doing so.[43]

[43] GIH (Global Infrastructure Hub). 2020. *PPP Risk Allocation Tool 2019 Edition*.

Box 6: Pan Am Games Athletes' Village in Canada

The project was developed to provide accommodations for the athletes and officials during the Toronto 2015 Pan American and ParaPan American Games. After the games the village became a mixed-use, inclusive and pedestrian-friendly riverside community that includes affordable housing. The Athletes' Village project significantly increased the pace of the West Don Lands revitalization and left Toronto with a beautifully designed lasting legacy of the 2015 Pan/Parapan American Games.

The project scope included:

- The design and construction of the Athletes' Village to provide accommodation for athletes and officials during the Toronto 2015 Games.
- Construction of new roads and services, such as hydro, sewer and water infrastructure.
- Conversion of the Athletes' Village into its post-games legacy state: a modern and sustainable neighborhood that includes market and affordable housing on Toronto's waterfront.

The project includes several design requirements that relate to disruptive technology, in particular an "intelligent community" element. According to RenewCanada, the "intelligent community" concept builds on the "smart city" idea but encompasses cities, metropolitan areas, and rural regions. The smart community concept is new and evolving because the number of communities using smart technologies to create economic opportunity and improve the quality of life for citizens continues to grow.

Accordingly, in the PPP contract the private partner is, for example, required to make ultra-broadband internet access available to all residential units. The private partner manages Beanfield Technology, the exclusive designated service provider to perform various services pertaining to the Intelligent Community system. In addition, the output specifications refer to best industry standards and require the project to perform the work so as to achieve LEED Gold Certification.

Source: GIH (Global Infrastructure Hub). 2019. Reference Guide on Output Specifications for Quality Infrastructure.

An **obligation to operate in accordance with best industry practice** as part of the performance requirements may impose some obligations on the private partner—to take on improvements in technology and to ensure that the infrastructure asset is interoperable with other infrastructure or equipment meeting prevailing industry standards (e.g., new technologies used as a standard for high speed trains may require upgrading of the infrastructure network).

Defining PPP output specifications that account for technological changes is difficult due to the rapid changes in technology and society. When it is unclear whether or not the technological advancement is or is not a new technical industry standard, if there are doubts about the value added, or if there is the perception that the requested change will lead to considerably higher costs for the private partner or its subcontractors, the most appropriate approach for PPP contract managers may be to treat these situations as contract variations. Also, a proper allocation of the risks associated with technological change suggests that more fundamental and unforeseeable advances in technology are regularly not addressed through output specifications (see also Section 4.1.3 (i) "Risk allocation").

> **If there are doubts whether or not the implementation of disruptive technology is a performance requirement or if the requested change results in considerably higher costs, the best approach for contract managers may be to treat these situations as contract variations.**

Considerations for Future PPP Contracts:

The private partner may in general be better placed than the contracting authority to absorb technological obsolescence risk. However, in light of a rapidly changing technological landscape, future PPP contracts may need to take a more nuanced approach. When defining the desired output, contracting authorities need to ensure that the output specifications (including technical requirements, and applicable codes and standards) set out in the PPP contract consider its long-term needs and anticipate changes that are reasonably predictable, such as advancements in battery storage technology or sensor technology for autonomous vehicles with regard to PPP road projects. The easiest way to ensure that the private partner can quantify its risk exposure while adding more flexibility to a PPP contract is to combine a precise description of the demanded output with a cap related to the costs for the technological upgrades or exceptions. If the PPP contract includes a broad variation mechanism, technical improvements that have major cost implications are thus treated as contract variations that are compensated. To incentivize the private partner to identify and implement the latest technology, PPP contracts can ensure that the private partner and the contracting authority share the benefits of any cost savings that are achieved through such innovations. This would also allow contracting authorities and the society at large to benefit from efficiency gains that result from technological progress (see also Section 3.2.2 (i) "Variations management").

(ii) Direct contractual obligation to adopt and/or integrate new technologies

In light of rapid technological advancement, some PPP contracts may already impose a specific obligation on the private partner to adopt new technologies for foreseeable developments, such as sensors for autonomous cars, charging stations for electric cars, or off-grid energy production.

(iii) Indexing and benchmarking

Supply contracts that are based on global market-based commodity prices are often indexed in the contract to allow for predictability during market fluctuations. The oil and gas industry, for example, relies on long-term contracts with oil or gas price indexes to stabilize the prices during periods of volatility. Exploring ways to index for disruptive technologies is one way to smooth out unpredictable price changes. In liberalized energy markets with corporate PPAs, for example, the COVID-19 crisis has pushed electricity buyers to consider various pricing structures beyond fixed-price. It is already common to incorporate escalation clauses for inflation or to account for foreign exchange fluctuations. Where there is a wholesale market price for renewable energy, other structures are being considered, such as discounts to market structure, wherein the buyer secures a discount to the market (fixed percentage or amount) over the duration of the PPA; in exchange, the buyer provides the power producer with a floor price, sometimes with a clawback to compensate the power producer if prices increase.

(iv) Term of the contract

PPP contracts are long-term agreements between the contracting authority and the private partner, often 20 to 30 years. During the term, the private partner finances and manages construction, maintains and operates the asset, and, at the end of the contract, transfers it back to the contracting authority. The idea of the long-term commitment is to maximize the efficiency of service delivery by incentivizing the private partner to integrate considerations related to future operation and maintenance into the design and construction phase. Most PPP contracts have a fixed term, i.e., unilateral adjustment is not possible unless the PPP contract includes specific provisions that state how the PPP contract can be terminated before the term ends.

Some contracts allow for more flexibility. One way to mitigate exogenous demand risk that is discussed with regard to PPP transport projects is to structure them as **present value-of-revenue (PVR) contracts**. Under a PVR contract, the regulator sets the discount rate and tariff schedule, and firms bid the present value of tariff revenue for which they desire to finance, build, operate, and maintain the infrastructure. The firm that makes the lowest bid gets the concession, which lasts until the present value of tariffs collected equals the winning bid. Consequently, the term of the concession automatically adjusts to demand shocks, resulting in a substantial reduction of demand risk borne by the concessionaire. PVR contracts are often used in Chile for PPP transport projects.[44]

Conversely, an extension of the contractual term can be helpful when a drop in demand leads to decreased revenue. When mobility restrictions during the COVID-19 crisis reduced the revenue of many transport PPPs under the "user-pays" PPP model, many private partners asked for an extension of the contractual term. In the report *Support Mongolia with Solar Energy Price Setting*,[45] the World Bank and the Energy Sector Management Assistance Program (ESMAP) recommended lowering feed-in tariffs that had become unattractive due to the global solar price drop, and offering the private sector investors an extension of the PPAs as an incentive to agree to these changes, so that they would still be able to recover the initial investment costs and achieve the targeted rate of return with a lower tariff (see "Case Study 1: Mongolia – Addressing Disruptive Technology Through Renegotiation and Energy Regulation"). A contract extension can also help the private partner to absorb costs of expensive technological investments (see "Case Study 6: Puerto Rico – Technological Upgrades and Contract Extension for P-22 and P-5 Toll Roads"). If the PPP contract does not provide for a contract extension under exceptional circumstances described in the contract, the extension needs to be renegotiated (see Section 4.2.4 (i) "Renegotiation").

> **"Contract managers may want to consider an extension of the contractual term to deal with decreased project revenue or to help the private sector to absorb costs for expensive technological investments caused by disruptive innovation."**

Considerations for Future PPP Contracts:

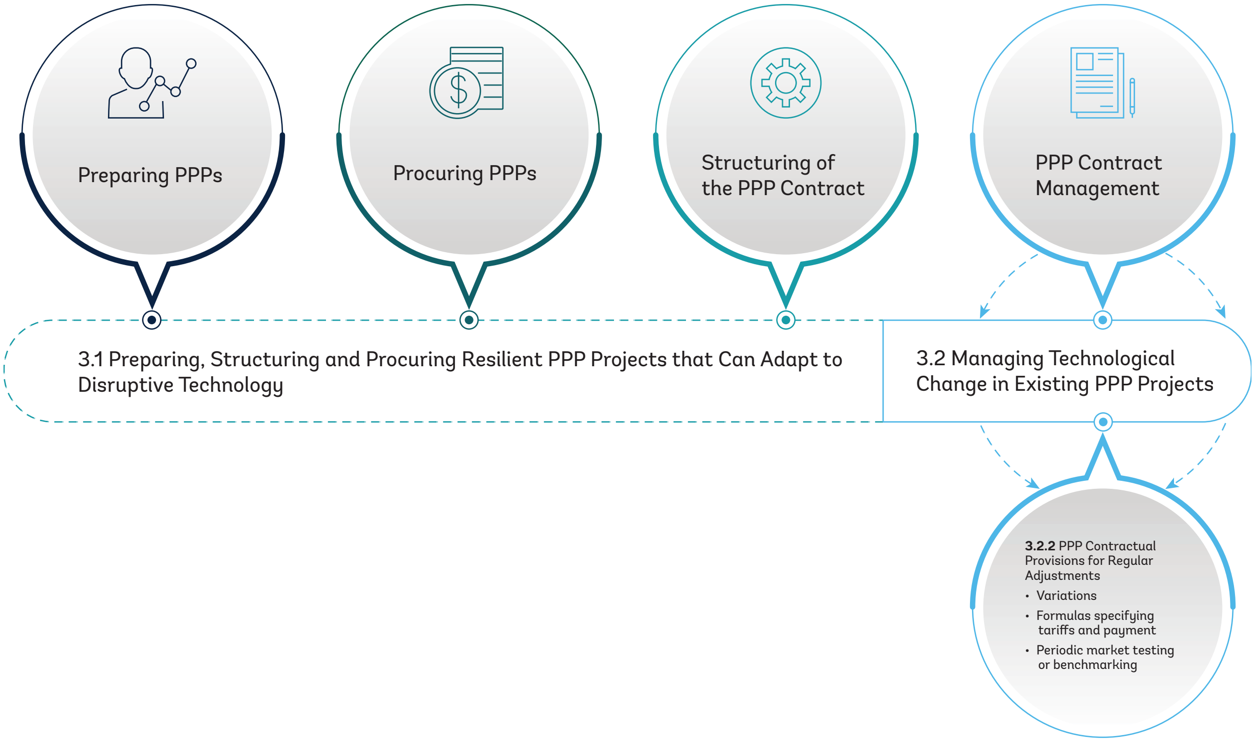
One way to mitigate exogenous demand risk that is discussed with regard to PPP transport projects is to structure them as **present value-of-revenue (PVR) contracts.**

It could also be advisable to switch to shorter terms or make contractual terms more flexible in sectors that are susceptible to technological change, should the financial model allow.

[44] Engel, Eduardo, Ronald D. Fischer, Alexander Galetovic, and Jennifer Soto. 2019. *Financing PPP Projects with PVR Contracts: Theory and Evidence from the UK and Chile.*

[45] World Bank and ESMAP (Energy Sector Management Assistance Program). 2018. *Support Mongolia with Solar Energy Price Setting: Final Report.*

3.2.2. PPP contractual provisions that permit regular adjustments



Due to the long-term nature of a PPP project, most PPP contracts contain provisions by which the contracting authority or the private partner can from time to time require certain changes to be implemented after contract signature.

These contractual provisions may sometimes be sufficient to address new developments in technology or longer-term changes that can make infrastructure projects obsolete long before the end of their expected life spans. Either party might, for example, require changes to the infrastructure assets or services, to reflect changes in public demand or propose innovative technology or cost saving measures, or request that tariffs and payments are adjusted to reflect economic changes.

(i) Variations management

The parties of long-term PPP contracts usually understand that circumstances may change over time. Therefore, it is good practice to include provisions that permit adjustments of the PPP contract from time to time. PPP contracts typically include a framework for the parties to request, negotiate, and agree to changes of the physical infrastructure asset or infrastructure services in response to changing circumstances that could not be anticipated or quantified when the PPP agreement was signed. This could also include changing technology. Variation provisions[46] usually contain a list of generic and undefined changes, and describe the variation procedure and how the costs of the variation are shared between the parties. They are the primary means by which PPP frameworks introduce flexibility into PPP contracts.[47] (See also "Case Study 3: Australia – Considering Future Technology Improvement of Victoria Water Desalination Plant.")

[46] Variation provisions are also known as change-order provisions, modification provisions, change in works, or change in service requirements.

[47] For details regarding variation during the operation phase, see the *APMG Public Private Partnership (PPP) Certification Guide*, Chapter 8, sub-section 7.

Considerations for Future PPP Contracts:

A broad variation mechanism within PPP contracts enhances flexibility with regard to technological upgrades. To ensure bankability, PPP variation mechanisms should, however, contain clear terms and conditions, in particular with regard to compensation and grounds on which the private partner may refuse to implement a variation. A good starting point to ensure a clear and adequate risk allocation between the parties within this framework may be to allow the contracting authority to request changes of works and services if it compensates the private partner for any additional cost or loss of revenue arising from these changes. At the same time, the contracting authority may want to share efficiency gains while still incentivizing the private partner to cooperate, explore, investigate, consider, and propose innovation through the variation framework. Advanced technology related to the adaptation or mitigation of climate change that was not known at the time the contract was signed may, for example, justify changes regarding the output specifications upon request by one of the parties. The variation mechanism can incentivize the private partner to identify and implement the latest technology if PPP contracts ensure that the private partner and the contracting authority share the benefits of any cost savings that are achieved through innovations.

(ii) Change management related to tariffs and payment rules or formulas

In a world of rapidly changing technology, governments need to ensure that PPP contracts are flexible enough to facilitate innovative solutions and business models in the interest of users, and that cost reductions through efficiency gains are shared between the public and private sectors. Likewise, if changes in technology affect costs and prices (e.g., falling renewable energy prices), contracting authorities or the private partner may wish to adjust tariffs or payments accordingly.

Tariffs or payments are often specified by **formulas**, to allow for regular adjustments for factors such as inflation. The PPP contract can also include mechanisms for reviewing these formulas—whether periodic, or one-off changes in extraordinary circumstances (with specified triggers) to reflect long-term changes. These processes are analogous to regulatory tariff reviews.[48]

Some PPP contracts require **periodic market testing** or **benchmarking of certain sub-services** in the contract, to allow costs to be adjusted to market conditions. This is typically done where a PPP includes provision of a long-lived asset (such as a school or hospital facility) together with sub-services that are frequently not offered in the market under long-term contracts (such as cleaning, catering, waste management, security and information technology services).[49] The objective of this requirement is to keep the price charged for the sub-service in line with market conditions.[50]

[48] World Bank Group. 2017. *PPP Reference Guide*, Version 3, p. 153.

[49] This approach is most common in PPP contracts in the United Kingdom Private Finance Initiative (PFI) tradition.

[50] World Bank Group. 2017. *PPP Reference Guide*, Version 3, p. 154.

Unilateral changes of tariffs or of availability payments are typically not permitted under PPP agreements. Consequently, contracting authorities cannot simply change tariffs agreed to under a PPA if falling prices of a technology (e.g., the price for solar photovoltaic (PV) panels has declined steadily during the past decade, leading to dramatic drops in tariffs) make the contracted tariff unattractive for the offtaker. In these cases, regulators may, however, be allowed (under the existing regulatory frameworks) to periodically revise tariffs that are applicable to future projects or to introduce new pricing schemes, with the objective of reducing the tariff to capture, for example, lower capital costs and other costs savings that have resulted from the more widespread adoption of that particular technology or switch to another type of technology.[51]

Regulatory mechanisms for price control can also provide incentives for innovation. Similar approaches could be considered for PPP contracts.

> **If disruptive technology upsets the economic balance of a PPP contract, contract managers need to check carefully whether the PPP contract establishes rules and processes for adjusting the tariff and whether these apply. Otherwise, sector regulators may be able to periodically revise tariffs or to introduce new pricing schemes to capture, for example, cost savings resulting from disruptive technology.**

Box 7: United Kingdom: Office of Gas and Electricity Markets (Ofgem)—Framework for Price Control Incentivizes Innovation

The Office of Gas and Electricity Markets (Ofgem) is a non-ministerial government department and independent national regulatory authority governed by the Gas and Electricity Markets Authority (GEMA). Ofgem sets price controls for the gas and electricity network companies. In Great Britain, energy networks are privately owned monopolies funded through consumer bills. Ofgem regulates the networks to make sure companies running the infrastructure invest intelligently and efficiently, while keeping costs to consumers as low as possible. To do this Ofgem uses price control mechanisms that set how much revenue network companies can recover from their customers, ensuring fair prices and a quality service.

Britain's energy sector is changing rapidly. Ambitious carbon reduction goals have led to major changes in how electricity is generated and how grids need to be managed. Going forward, Britain needs to integrate new technologies like electric vehicles (EVs) and heat pumps, and make low-carbon, often weather-dependent, power available in the right places and at the right times. Innovation is therefore increasingly affecting how energy is produced, transported, managed and consumed. Given the increasing scope and range of potentially transformative and disruptive new business models and innovative solutions, Ofgem is continuously updating its regulatory approach to ensure that it is sufficiently flexible and agile to facilitate innovations in consumers' interests, while maintaining the protections required of an essential service.

To create an environment conducive to innovation required for the energy transition, Ofgem replaced its old RPI-X price control model[52] in 2013 with a new performance-based framework. The new regulatory framework is based on the RIIO principle (Revenue = Incentives + Innovation + Outputs). RIIO sets targets to encourage more innovation and extends the tariff adjustment scheme from five to eight years with the objective of providing more incentives to adopt innovations that reduce costs and improve services to users.

Source: Ofgem. *https://www.ofgem.gov.uk.*

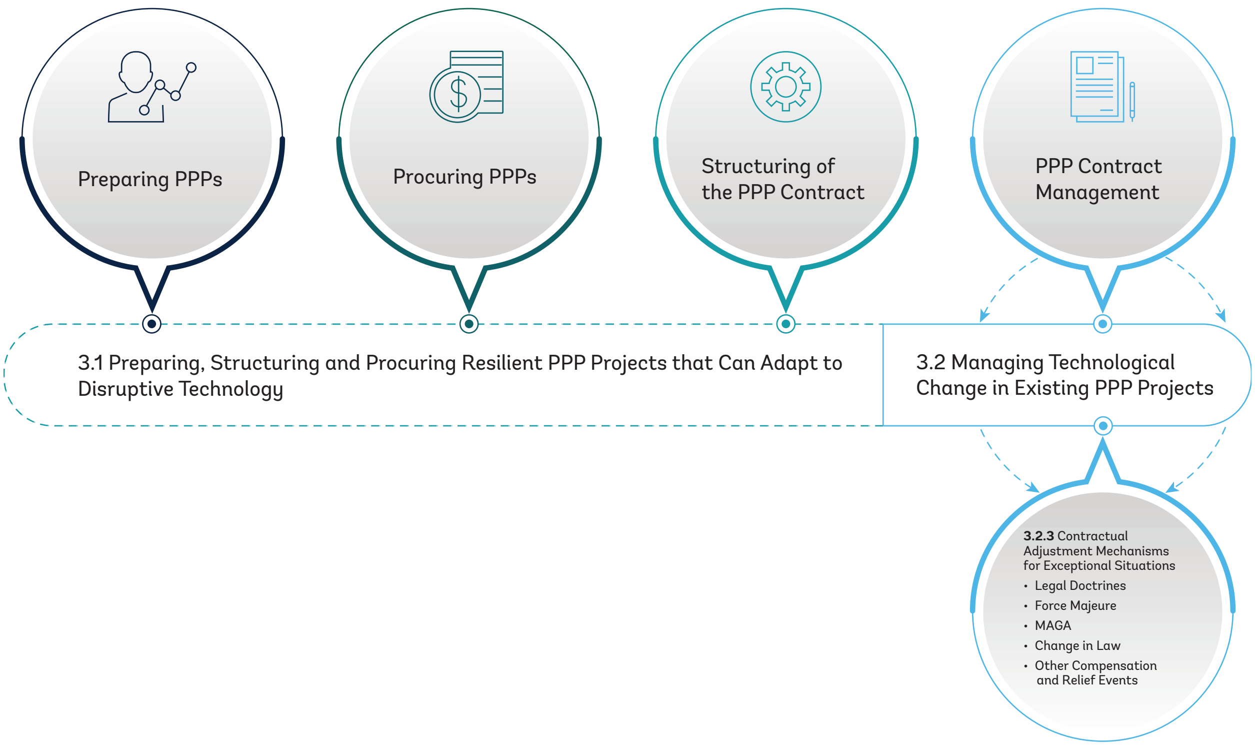
[51] Africa Legal Support Facility. 2019. *Understanding PPAs,* Second Edition, p. 105 f.

[52] Retail price index (RPI) minus efficiency saving target (X).

Considerations for Future PPP Contracts:

To protect both parties against unforeseen economic effects of disruptive technology and to incentivize the adoption of innovation, contracting authorities could consider extending provisions that make tariffs or payments dependent on specific formulas in tariff adjustment schemes to factor in economic effects caused by technological disruption and to incentivize innovation. With regard to specific sectors or sub-services, requiring periodic market testing or benchmarking might be justified to allow costs to be adjusted to market conditions.

3.2.3. PPP contractual provisions and legal mechanisms that permit adjustments in exceptional situations



A long-term unexpected change of circumstances brought on by new technologies might also disrupt the economic underpinnings of a PPP contract fundamentally. This can make it difficult for one party to perform according to the contract or even result in the parties being unable to fulfill their contractual obligations. Generally, a failure by one party to perform contractual obligations gives the other party remedies, including the right to claim compensation or to terminate the contract.

However, where the changed circumstances upset the balance of contractual obligations, legal doctrines that are applicable in a number of jurisdictions may give the parties the right to adjust the PPP contract to the new and unexpected conditions. Parties to a PPP contract often agree upfront on a risk allocation that mirrors these legal doctrines to some extent. PPP contractual provisions that can be found in almost all PPP contracts deal with the consequences of a number of specified events that are outside the control of one or both parties, in particular force majeure or MAGA events or change in law. Under these contractual provisions, one or both of the parties may be excused from the performance of certain contractual obligations in whole or in part, or entitled to suspend performance, to claim an extension of time for performance, to claim compensation, or to terminate the contract.

(i) Legal concepts underlying contractual adjustments

Changed circumstances prompted by disruptive technology may give the parties the right to adjust the contract under certain legal doctrines.

> **Contract managers need to consider whether changed circumstances prompted by disruptive technologies give one or both parties the right to rebalance the economic equilibrium of the PPP contract under certain legal doctrines that are either spelt out in the PPP contract or are part of the underlying governing law.**

In some civil law countries, these legal concepts are part of the national law that is applicable to a PPP contract. In other cases, the concepts have become part of the PPP contract. Although it is more usual, in particular in common law jurisdictions, to deal with a change of economic conditions through variation regimes, force majeure, MAGA and change in law provisions (as detailed in the previous section and below), some PPP contracts have included the underlying equitable principles of these legal principles explicitly or indirectly, by reference to the project economic and financial scenario updated in accordance with a project accounting plan and key economic indicators.

These legal concepts are applicable to new, unexpected conditions of various kinds, and can significantly mitigate the risk to the private partner in case of major changes caused by technological disruption. They may, however, also be activated in favor of the contracting authority.

Under these legal principles, the private partner facing an excessive loss that threatens to strand the asset may be allowed to request an adaptation of the contract to the new conditions to restore the economic balance of the contract, up to a certain threshold. Typical legal mechanisms that can be found in PPP contracts and legal doctrines that have already been invoked by contractual parties in the context of disruptive events in the past are summarized below.[53]

(a) **Restoration of the economic equilibrium** In many jurisdictions, in particular in France and those influenced by the French Civil Code, notably in francophone Africa, the parties of a PPP contract have the right to adjust the contract to new, unexpected conditions and to "restore the economic balance" of the contract, irrespective of the existence of a contractual provision **(right to financial equilibrium)**. Economic rebalancing refers to the practice of modifying the financial conditions that were agreed as part of the original contract. The intention is to preserve or restore the original economic equilibrium of the PPP contract. Rebalancing mechanisms are stipulated in many civil law jurisdictions (e.g., several countries in Latin America). In comparison to similar provisions in common law jurisdictions, they are more fluid mechanisms to deal with a variety of issues, including a force majeure event, a scope change, change in macro-economic conditions, change in law, or a major change to demand. The adjustments can be ad hoc responses to external events, such as a change in the rate of inflation, or be the result of contract renegotiation.[54] For example, if the implementation of new tolling technology in a road project increases toll revenue in a PPP road project, the contracting authority could invoke the doctrine to achieve a sharing of excess profits or a reduction to the contract period, or to ask the private partner to lower the user tariff.

[53] Trinity International LLP. 2020. *Covid-19 – implications under French Law and guidelines for future project finance transactions*; World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, S. 29.

[54] GIH (Global Infrastructure Hub). *PPP Contract Management*.

The legal consequences range from a temporary relief from contractual obligations; an adjustment of the legal obligations to restore the economic balance up to a certain threshold (e.g., payments by either party); or compensation; up to a termination of the contract.

(b) **Hardship doctrine** Hardship doctrines are typically civil law principles that provide the private partner with relief where the contract circumstances have changed due to events that were unforeseeable, beyond the parties' control, and that have a fundamental impact on the economic balance of the contract. French law, for example, allows a party to invoke the **doctrine of hardship (imprévision)** if there has been a change in circumstances unforeseeable at the time of conclusion of the contract that makes performance of the contract "excessively onerous" for one party that had not agreed to assume the risk.[55] The affected party may request a renegotiation of the contract from the other party (e.g., to increase the contract price). Performance of the contract shall continue during the renegotiation. If the renegotiation is refused or if it fails, the parties can mutually agree to terminate the contract or ask the courts to adapt it. If an agreement cannot be reached within a reasonable time frame, the court can, upon request by one of the parties, revise the contract or terminate it, e.g., if the price increase is too significant or the situation is likely to last indefinitely.[56] Parties may, however, derogate from this provision if they wish to do so. Market practice may exclude the doctrine of hardship in PPP contracts in order to provide certainty and instead rely on specific provisions in the contract.

[55] Article 1195 of the French Civil Code.

[56] Trinity International LLP. 2020. *Covid-19 – implications under French Law and guidelines for future project finance transactions*; World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, S. 29.

Box 8: Legitimate Expectations under the Energy Charter Treaty

Following the financial crisis of 2008, the legitimate expectations doctrine under the Fair and Equitable Treatment clause in the Energy Charter Treaty (ECT) was the basis of several claims by renewable energy developers against contracting authorities in Spain, Italy, and the Czech Republic. Spain and Italy, for example, had issued attractive incentives for investing in renewable energy before 2008, which were then rolled back in the years following the crisis. Many cases were brought under the ECT based on the legitimate expectations set by these incentives (set out in the legal and regulatory framework or through representations to the investor).

Though tribunals have been split on this matter, many tribunals have sought to balance the competing interests between the investor and the state. In Charanne B.V. (Netherlands) Construction Investments S.A.R.L. (Luxembourg) v. The Kingdom of Spain, for example, the tribunal cited the good faith principle of customary international law a rule according to which host states cannot induce foreign investors to make investments based on "legitimate expectations" then later ignore the commitments that served as the basis for these legitimate expectations. It also established that legitimate expectations should be based on an objective standard, and that investors should exercise due diligence when investing (including meeting the standard of a "prudent investor"). Furthermore, it found that the expectations should be reasonable and proportional. Namely, the tribunal noted that no investor can expect from the host state that it will not change its regulatory framework in the public interest, and there was no promise from the state that the tariff regime would remain untouched for the entire life of the plant (had there been a stabilization clause in the treaty or in the investment agreement, it may have been read differently). At the same time, the investor has a legitimate expectation that, when modifying the existing regulation based on which the investment was made, the state will not act "unreasonably, disproportionately or contrary to the public interest." Where the state did reduce the reasonable return of the investor, as was the case in PV Investors v. Spain, the tribunal found for the investors.

(c) **Legitimate expectations and fair and equitable treatment** The doctrine of legitimate expectations is generally recognized as a part of the Fair and Equitable Treatment clause found in many investment treaties. The concept of legitimate expectations arises "where a Contracting [Authority]'s conduct creates reasonable and justifiable expectations on the part of an investor (or investment) to act on reliance on said conduct, such that a failure by the [Contracting Authority] to honor those expectations could cause the investor (or the investment) to suffer damages."[57] The arbitral tribunals looking at these cases have found that the contracting authority can create these expectations in several ways: (i) through contractual rights, (ii) formal and informal representations to the investor (noting that certain tribunals further stipulate that these representations must be specific), and (iii) the general regulatory framework in force at the time of the investment. Importantly, the need for states to maintain a stable and predictable regulatory framework is not absolute, and is limited by the state's sovereign right to regulate in the public interest. The specific context matters too when tribunals have looked at legitimate expectation claims: developing countries in transition, for example, cannot be expected to have legal regimes as stable as those of developed countries.

[57] *International Thunderbird Gaming Corporation* v. *The United Mexican States.*

(d) **Doctrine of frustration of purpose** The principle of frustration refers to situations in which performance of a contract becomes worthless to a contracting party. Such a principle was sometimes invoked successfully in litigation related to COVID-19 and may also become relevant with regard to impacts caused by other disruptive events. The doctrine applies whenever circumstances that have become the basis of a contract have changed in a way that makes it unbearable for one party to perform its obligations under the terms of the contract. The changes must so **significantly alter the nature of the outstanding contractual rights and/or obligations** from what the parties could reasonably have contemplated at the time the contract was made, that it would be **unjust**, in the new circumstances, to hold them to the contract's literal wording. The parties may only invoke the doctrine, however, in exceptional cases. It is not sufficient that the performance of contractual obligations becomes more expensive or more difficult for one party. The changes must also be neither within the control of the parties nor have been foreseeable by the parties at the time they entered into the contract. In these cases, the party affected may be permitted to stop performance or to request adjustment of the contractual terms to the new circumstances considering their contractual intent as far as possible. The range of possible contract amendments is wide and could, e.g., include an adjustment of pricing rules, delivery obligations or technical and operational rules. Amendments may also terminate the contract if the contract cannot be adjusted or if it would be unreasonable to do so. Additional consequences, e.g., compensation for any valuable benefit provided, differ depending on the jurisdiction and national legislation.

(e) **Doctrine of impossibility** The doctrine of impossibility may be used as a defense in situations where the actual performance of the contract has become impossible. Much like frustration of purpose, there are strict requirements that must be met to invoke this defense, namely the occurrence of a supervening event, the non-occurrence of which was a basic assumption on which both parties made the contract, that makes performance under the contract impossible (or impractical). Mere unprofitability is not enough to render performance impossible.[58] The doctrine has, for example, sometimes been invoked successfully by businesses in connection with impacts caused by COVID-19. If the doctrine is applicable for a specific PPP contract, it could help in a situation where the performance of contractual obligations, e.g., operation of a port, has been made impossible due to a mandated lockdown.

Considerations for Future PPP Contracts:

Whether or not legal doctrines that allow for a rebalancing of the economic equilibrium of the PPP contract are applicable and to what extent depends on the underlying governing law. For long-term PPP contracts, it can be advisable to spell out legal concepts that govern a PPP contract in a specific jurisdiction to achieve more clarity for both parties. Depending on the circumstances [and the specific jurisdiction], equitable principles could also be integrated into PPP contracts in jurisdictions where such principles are not mandated by law, to provide better protection for both parties in environments that are continuously changing due to technological progress, e.g., by referencing the project's economic and financial scenario (which is updated from time to time) and key economic indicators.

[58] Dressel Malik Schmitt LLP. 2021. "Covid 19, Frustration of Purpose and Impossibility." (Last visited September 13, 2022.)

(ii) Force majeure

Several remedies exist in established contract law and PPP practice that are designed to deal with **sudden shocks and emergency situations.** If disruption in connection with new technologies prevents either party's ability to perform their obligations under the PPP contract, both parties may be able to invoke force majeure provisions.

Force majeure events are events beyond the control of the parties that render the performance of all, or a material part, of one party's obligations impossible.[59] The aim of force majeure provisions in a PPP contract is to allocate the financial and timing consequences of force majeure events between the parties. The starting assumption is that the risk of a force majeure event is a shared risk because it is outside both parties' control.[60] Each party will typically bear its own consequences of a force majeure event.

> **With regard to cyber attacks contract managers need to check carefully whether these are expressly mentioned in the list of force majeure event. If not, a catch-all definition may include scenarios where cyber incidents lead to widespread disruption that makes performance of the PPP contract impossible.**

Whether or not the parties can invoke force majeure provisions depends on the specific wording of each PPP contractual provision, the situation, and the definition of **force majeure events**. Usually, a force majeure clause will list out specific events that qualify, such as political events (war, strikes, protests) and natural disasters (floods, earthquakes, hurricanes, other "acts of God"). The definition often focuses on events that are uninsurable, outside of the control of either party, or catastrophic in nature.

Force majeure clauses may specifically mention cyber attacks, but often they are not expressly included in the list of force majeure events. If the PPP contract contains an open-ended catch-all definition that includes all events beyond the reasonable control of the affected parties, the provision may cover scenarios where cyber incidents lead to widespread disruption that makes performance of the PPP contract impossible.[61] Many of the adverse consequences described above that may increasingly affect PPP contracts as a result of rapidly changing technology,[62] such as a drop in demand or obsolescence, are, however, very different in nature to the types of events that are listed in a standard force majeure provision and will therefore not qualify as a force majeure event.

> **Contract managers need to keep in mind that force majeure provisions are generally interpreted strictly and narrowly. It will usually not be sufficient for a party to claim that a cyber incident has made the performance of contractual obligations more expensive or more difficult to invoke the provision.**

In order to invoke force majeure provisions, a force majeure event must further prevent a partner from fulfilling its obligations under the contract. The **inability to perform obligations under the PPP contract** may be caused directly by the disruptive event, e.g., a cyber attack prevents the operation of an airport for an extended period of time. Alternatively, the disruptive event may have indirect consequences, such as a fall in demand, rising costs, liquidity issues, or delays in the supply chain, which may make it impossible for a party to perform its obligations under

[59] At times the standard for relief is less than "impossibility"; for example, contracts may use lesser standards, such as "adversely affecting" or "preventing." World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*

[60] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 27.

[61] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 31 f.; World Bank Group. 2021. *Covid-19 and PPPs Practice Note*.

[62] See Section 3.3.3.

the PPP contract. Force majeure provisions are, however, generally interpreted strictly and narrowly.[63] It will usually not be sufficient for a party to claim, for example, that a cyber incident has made the performance of contractual obligations more expensive or more difficult.

If force majeure is invoked, the contract may specify that the parties meet to draw up any **mitigation measures** and to **negotiate any possible relief**. The availability of insurance to cover the event and the duration of the force majeure event will affect what types of and how much relief is available.

The most basic relief is an **excuse from performance** on the part of the party invoking force majeure. Relief may or may not also include **compensation** in terms of ongoing payments, extension of contract, a reduction in the performance requirements, or increase in tariff (corresponding to costs related to force majeure), depending on the circumstances and the risk allocation in the contract. Usually, the affected party will need to demonstrate ongoing mitigation efforts to qualify for any relief. As a contractual provision (rather than relief provided under statutory or common law), force majeure clauses can vary widely and the scope of events that qualify as force majeure and the relief available to a party impacted thereby will depend upon the specific language used in a contract. If force majeure is continuing for a specific amount of time, then either party may seek to **terminate** the contract.

Force majeure provisions and their interpretation have recently received a lot of attention in relation to **climate shocks and stresses**. Historically, natural disasters have been considered force majeure events that are out of the control of all PPP parties. However, with the increased frequency of **climate change-related disasters**, it is more often acknowledged that infrastructure assets of the future need to be resilient to climate change, i.e., need to be planned, designed, built and operated in a way that anticipates, prepares for, and adapts to uncertain and potentially permanent effects of climate change. Against this background, it may not be justified to treat more foreseeable shocks and stresses that have become more likely due to climate change as force majeure going forward, while exceptional climate events may still qualify as force majeure events.[64] This risk allocation will also incentivize adaptation measures and enhance resilience.

[63] Schwartz, A. 2020. "Contracts and COVID-19." *Stanford Law Review* 73.

[64] Global Center on Adaptation. 2021. *Climate-Resilient Infrastructure Officer Handbook*, p. 153.

Box 9: Japan—PPP Contracts Include Nuanced Force Majeure Definition Building on Experience from Previous Disasters

The "Guidelines for Contract: Points to Consider for PPP Project Contracts" released by Japan's PPP/Private Finance Initiative (PFI) Promotion Office include a standard force majeure definition. However, this standard definition is refined for each project or area, taking into account the characteristics and site conditions of each project. For example, Sendai City has iteratively clarified the contractual force majeure provisions based on lessons learned from various earthquakes and increasing project experience, and specified the seismic intensity as a numerical standard above which an earthquake is regarded as a force majeure event. In the Aichi Road Concession Project, the contracting authority defined, for instance, precisely the threshold that renders a natural disaster a force majeure event for which it bears additional costs if the concessionaire cannot foresee or cannot be reasonably expected to establish measures to prevent additional costs.

Source: World Bank, Tokyo Disaster Risk Management Hub, and Global Infrastructure Facility. 2017. Resilient Infrastructure PPPs, Contract and Procurement: The Case of Japan, Solutions Brief.

Likewise, **epidemics and pandemics** are treated in some PPP contracts as force majeure events,[65] whereas the provision could not be invoked in other jurisdictions with regard to the COVID-19 pandemic.[66] In the latter case the contracting parties could often rely on legal principles, such as the **doctrine of impossibility or hardship clauses**. Going forward more nuanced provisions that take potential precautionary measures into account may be necessary.

Similar considerations apply if the increased use of disruptive technology together with a high level of connectivity makes the risk of **cyber attacks** that target infrastructure assets during the duration of a PPP contract more likely. They may not apply if the impact could have been prevented or mitigated by reasonable precautionary cyber security measures.

> "Contract managers need to be aware of the connection between cyber risk management and force majeure provisions as the applicability of force majeure provisions in the event of a cyber incidents may increasingly depend on whether or not the adverse impact could be prevented or mitigated by reasonable precautionary cyber security measures."

[65] On April 15, 2020, the Office of the General Counsel within the Ministry of Infrastructure in Brazil recognized COVID-19 as a force majeure event in order to allow claims related to the rebalancing of federal concession contracts (APP) in the sectors that fall within its jurisdiction, e.g., transport. However, the federal regulatory agencies in Brazil, e.g., the Electric Energy National Agency, discussed the rebalancing of concession agreements considering the COVID-19 pandemic. World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*

[66] According to the *Guidance Note* released by the Infrastructure and Projects Authority (IPA) of the United Kingdom on April 2, 2020, in the context of Private Finance Initiative (PFI) and Private Finance 2 (PF2) projects, the government does not regard COVID-19 as an event of force majeure.

Considerations for Future PPP Contracts:

It will be important to assess and allocate potential risks created by disruptive technology and clearly define the atypical and extreme events that should fall within the ambit of the force majeure provisions together with thresholds and exceptions where appropriate and what the consequences are for each. To increase certainty and depending on the level of risk, contracting authorities should, for example, expressly mention cyber attacks as force majeure events. To ensure that cyber incidents that can be anticipated and prepared for do not qualify as force majeure events and to promote the adoption of cyber risk-reducing actions, PPP contracts should also describe under which circumstances cyber attacks should be treated as shared risk events, i.e., concrete precautionary and mitigating measures.

(iii) Material adverse government action (MAGA)

A relative of force majeure, the material adverse government action (MAGA) provision is designed to provide relief to the project company where the government has taken or omitted an **action** that has a **material adverse effect** on the project company, such as its financial standing, through **no fault** of the project company. The provision allocates certain agreed types of political risk to the contracting authority, addresses the **consequences** of such risks occurring, including possible termination, and provides the private partner with appropriate compensation.[67]

MAGAs, also known as political force majeure **events**, are events—such as wars, riots, or expropriations or failures of governments to grant permits—that prevent the private partner from fulfilling its obligations under the contract. They often encompass change in law as well.

Where the government takes action to prevent or respond to disruptive events, the parties may be able to invoke MAGA provisions. These could include an embargo or restrictions on movement, foreign exchange controls, or even nationalization (direct or indirect). Disruptions caused by cyber criminals, which have become a realistic threat for the provision of essential infrastructure services, may lead to a government action that qualifies as a MAGA event.

In addition, unilateral changes of the support mechanism that alter the economics of the project can make a project that was initially very attractive for the private partner completely unattractive and give it the right to invoke MAGA or change in law provisions (for details on change in law provisions, see Section 4.2.3 (v)). For example, to attract investment in renewable energy projects, governments have in the past often offered a variety of support mechanisms, primarily as subsidies or attractive tariff arrangements. Renewable energy projects have been vulnerable to changes of these favorable conditions over the term of the contract. These policy changes can have different causes, such as plummeting renewable energy prices or changing macroeconomic circumstances. During the 2008 global financial crisis, for example, many European countries retroactively reduced the financial support afforded to investors in solar PV projects.

> **"Contract managers need to bear in mind that unilateral changes of subsidies or other support mechanisms that promote innovation may make the project unattractive for the private partner and give it the right to invoke MAGA or change in law provisions."**

[67] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 49.

When discussing whether an event is "**material**," the following generally needs to be considered

- Is it a substantial change?
- Is it a significant change?
- Is it for a significant period of time?

The extent to which a government action qualifies as a MAGA will depend on how the terms are defined under the contract, as well as the reasonableness of the actions and the outcomes of negotiations.[68] Similar to force majeure provisions, MAGA provisions should clearly and specifically define the events and circumstances for invoking the clause and the rights and obligations of the private partner.[69]

Although project sponsors are expected to take commercial risks, drawing a line can be difficult; hence specific and narrow drafting of such clauses is advised, for example, using a defined list of covered events, not only to avoid disputes in their interpretation, but also to limit the extent of liability of the government under such clauses.[70]

Regardless of the definition, such events are distinct from force majeure in that they are considered within the government's control and therefore the onus is usually on the government to "make whole" the private partner if it suffers any damages.[71] Some MAGA events that cannot be controlled by either party are typically treated as shared risk similar to force majeure.

Remedies may include relief from performance (including payment of delay liquidated damages where there may be delays), extension of time, and compensation for costs incurred as a result of the MAGA. However, where the government feels forced to take action as a response to circumstances that are not in its control, it is not clear whether this clause can be invoked instead of force majeure—though, it is possible the private partner will try, given that the remedies are usually better than under force majeure.[72]

Considerations for Future PPP Contracts:

Similar to force majeure provisions, atypical and extreme events that fall within the scope of MAGA provisions and could become more frequent in relation to emerging technologies should be defined clearly—together with thresholds and exceptions so that the parties have suitable mechanisms within the PPP contractual framework that incentivize the implementation of precautionary measures, as well as appropriate response and mitigation plans that facilitate finding a balanced solution for both sides in case such an event occurs.

[68] World Bank Group. 2021. *Covid-19 and PPPs Practice Note*.
[69] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, Chapter 2.
[70] World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*
[71] World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*
[72] World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*

(iv) Insurance

> Contract managers need to keep track of cyber insurance programs and the use of mandatory cyber insurance provisions. The availability of insurance may influence whether or not the occurrence of a cyber incidence will be eligible for compensation under force majeure provisions.

Insurance plays a key part in managing force majeure and MAGA events, in particular climate change risks and risks posed by disasters and other unforeseeable events.

Under some PPP contractual frameworks, the private partner is the main bearer of disaster risks and is mandated by the contract to purchase necessary **insurance** to transfer such risks to the insurance market. Though insurance plays a key part in managing climate change risks and risks posed by natural disasters, it has its limitations when it comes to the economic risks that may be the consequence of technology disruption, such as business interruption or decrease in demand caused by disruptive technology, which usually are not covered by insurance policies.[73] Cyber insurance programs are still not common but have gained more traction in recent years. Mandatory cyber insurance could play a more important role going forward for PPP infrastructure projects to deal with exponentially increasing cyber risks caused by rapid digitization.

Box 10: Mandatory Insurance for Natural Disasters for PPPs in Chile

Chile sits on the Ring of Fire and has some of the most seismically volatile land in the world. The earthquake risk in Chile is therefore high during the course of a PPP. Because of their frequency, earthquakes are not considered as force majeure events under the PPP Law in Chile (*Public Works Concession Law and Regulations - Ley y Reglamento de Concesiones de Obras Públicas*). Instead, the PPP Law requires concessionaires to take out insurance that covers catastrophic risks that may occur during the term of the concession. The insurance payments obtained need to be allocated to the reconstruction of the asset, unless agreed otherwise. The concessionaire must repair the asset in its entirety and cannot claim reimbursement from the government. However, with regard to catastrophic events, the parties can contractually agree to share the losses.

On February 27, 2010, Chile experienced an 8.8 magnitude earthquake, the second largest earthquake in its history. The earthquake caused significant land damage and triggered a tsunami that caused severe coastal damage. The United States Geological Survey estimated total economic loss as a result of the earthquake and tsunami at US$30 billion. The earthquake damaged and destroyed infrastructure, with losses estimated to be equivalent to US$21 billion. However, because most of the physical damage to ports, bridges, and roads built through PPPs was insured, the fiscal impact of the earthquake on the government in relation to these infrastructure projects was minimal.

Sources: Ley y Reglamento de Concesiones de Obras Públicas, Articulo 36 et 75 *(Public Works Concession Law and Regulations,* Article 36 and 75); PPP Knowledge Lab. Climate Change and Natural Disaster.

[73] Measures taken during the COVID-19 pandemic to limit the spread of the virus have, for example, significantly disrupted economic activity in countries around the world. This had major implications for infrastructure projects, including those financed through the PPP model, such as business interruption, decrease of demand, and supply chain issues. These pandemic-related losses were, however, typically not covered by insurance policies taken out by construction firms or infrastructure operators.

(v) Change in law

In a PPP project, the private partner will typically be expressly obliged under the PPP contract to comply with all applicable laws. An unexpected change in law may make the performance of its contractual obligations easier and less expensive—or may make it nearly impossible, delayed or more expensive.

Changes in law provisions can, for example, become relevant when technological advancements require policy changes, if prices for technology are changing rapidly, or if new rules for an infrastructure developer or operators aimed at mitigating cyber risk are introduced.

- As a general rule, the private partner typically has to deal with the risk of a **general change in law** that affects any business and bear the costs of such changes. A legal requirement for all businesses to use electric cars would, for example, qualify as a general change of law.
- However, if the change in law applies to the PPP project only **(discriminatory change of law)** the contracting authority may have to grant relief from the breach or compensate the private partner for additional expenses. In these cases, if the change in law gives the private partner the right to terminate the contract, the contracting authority will have to pay termination payments that are similar to contracting authority default.[74]
- Changes that only affect the specific sector in which the project company operates are known as **specific changes in law**. Mandatory technological enhancements are typically treated as specific changes in law. With regard to specific changes in law, there is a wide divergence of practices. A common approach is to share the risk—but to always provide a cap on the overall exposure of the private partner, so the risk is quantifiable.

Considerations for Future PPP Contracts:

Regulatory standards related to technology vary over time, and governments should not be prevented by long-term contracts with private partners from improving regulatory requirements to achieve higher efficiency, better safety standards, lower carbon footprints, or other public interests. However, it is considered best practice to limit or share the risk of the replacement or overhaul of technological equipment or systems, and any other cost related to regulatory technical enhancement—unless the requested technological upgrade is affecting the general economy and any type of business. If the new legal obligation was not possible to anticipate at the time of the contract execution, and this adversely impacts in a material form the financial equilibrium of the project, it is good practice to establish a financial relief mechanism in the contract to share and limit the cost impact.

Change in law provisions should also define what qualifies as change in law, i.e., the types of "law," qualifying date and what qualifies as a "change," the approach to risk allocation, and the consequences in the event a change in law occurs. The term "law" is usually defined broadly (laws, regulations, government policies).

See also *Guidance on PPP Contractual Provisions,* World Bank 2019, Chapter 3.

[74] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 59 ff.

How requests to change equipment to adapt to new technologies are dealt with depends on the specific circumstances and contractual provisions. For example, the private operator of a high-speed rail system may be obligated to implement new technologies if the enhancement has become best industry practice. In other cases, the contracting authority may be able to request a technological change under the variation provisions or, if the enhancement is prescribed by law or sectorial regulation, request the change as a legal requirement which could give the private partner the right to invoke change in law provisions. Sometimes, change in law is also captured under the material adverse government action provision (see Section 4.2.3 (iii)).

> **It needs to be decided on a case-by-case basis how requests to change equipment to adapt to new technologies can be dealt with under the PPP contract. If the enhancement is prescribed by law or sectorial regulations the private partner may have the right to invoke the change in law provision.**

(vi) Compensation and relief events

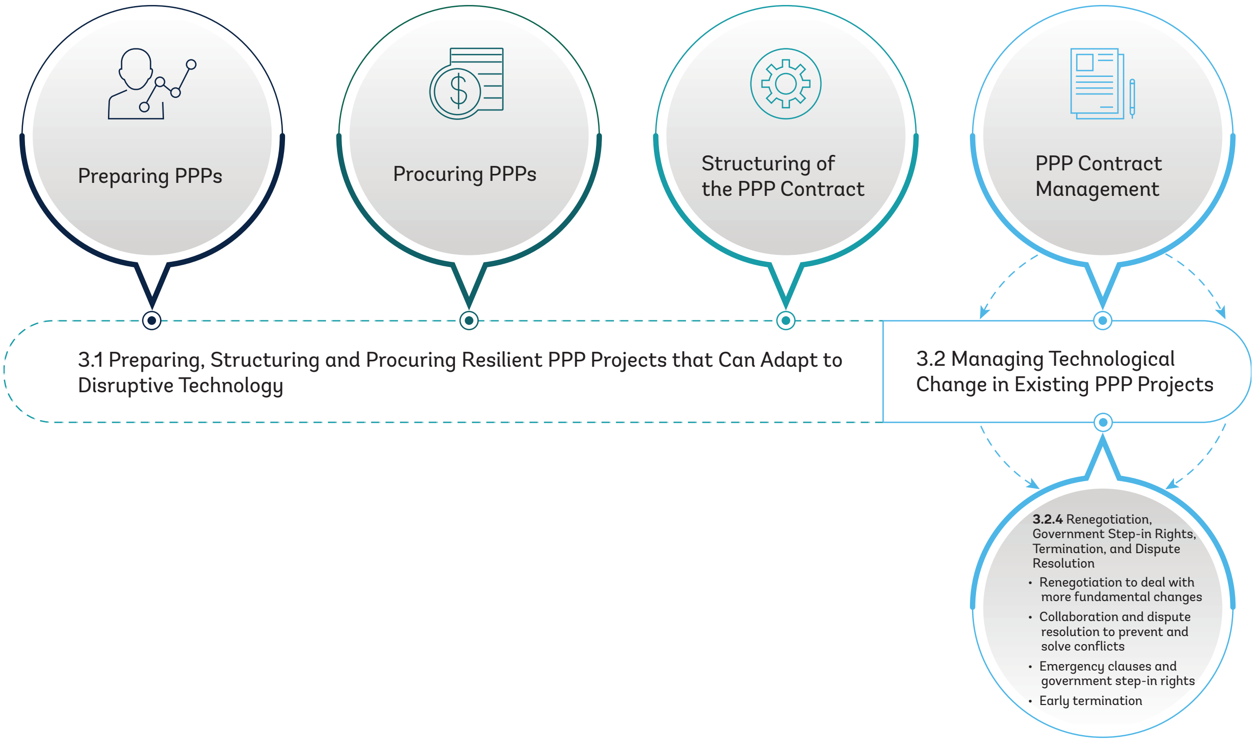
A PPP contract generally gives the private partner the right to claim compensation and time relief for certain defined events. Typically, these involve situations where the private partner has incurred unanticipated costs or delays, due to acts or omissions of the contracting authority or a third party, or due to force majeure events.[75] PPP contracts typically distinguish between compensation and relief events:

Compensation events are events for which the contracting authority broadly takes the risk because it is better placed than the private partner to bear or manage the risk. To the extent that the compensation event occurs during the term of the PPP contract, the private partner will be afforded sufficient protection in the PPP contract. The contractual protection varies and can, for example, be an extension of time, compensation, or any other form of contractual relief required to put the private partner back into the position it would have been in had the compensation event not occurred ("no better, no worse"). This principle applies to a number of contractual risks for which the contracting authority is responsible. Typical compensation events are discriminatory changes of law or authority failures.

Relief events are generally external events that are outside the control of the private partner, which have a negative effect on the capacity of the private partner to perform its obligations under the PPP contract. They typically cause delays or increased costs beyond those anticipated in the financial model. They are also called **delay events** if they occur during the construction phase. Relief events are events for which the private partner is expected to take financial risk in terms of increased costs and reduced revenue but is given relief from other consequences of non-performance that such events cause, e.g., an extension of a deadline. These are, by nature, events that are either insurable or not expected to continue for many days. They typically include power or fuel shortages, accidental loss or damage to the project, and events such as fire, storms and floods, to the extent these are not covered by other contractual provisions. Temporary force majeure events, such as a cyber incident or non-discriminatory change in law caused by disruptive technology, may be treated as relief events.

[75] As described above, under force majeure (Section 4.2.3 (ii)), MAGA (Section 4.2.3 (iii)), and change in law (Section 4.2.3 (v)), disruptive technology may lead under certain circumstances to compensation or relief events that need to be managed.

3.2.4. Renegotiation, government step-in rights, termination, and dispute resolution



If the applicable adjustment mechanisms do not resolve the issue caused by disruptive technology, the parties may still want to find out if they can continue the project by revising the terms of the PPP contract for the long term through renegotiation. It is, however, always possible that the disruption has made the project so difficult that one party seeks to terminate the contract or that the contracting authority decides to step in. In cases where the parties do not agree—for example, on the interpretation of output specifications or adjustment mechanisms provided for in the PPP contract—and renegotiations fail, or one party is not interested in solving the conflict through renegotiations, then the disagreement between the parties may need to be resolved through the dispute resolution mechanisms described in the contract.

(i) Renegotiation

The contractual adjustment mechanisms described above together with legal principles that may apply to the PPP contract in a specific jurisdiction provide some flexibility to deal with changes in circumstances that were not anticipated when the parties entered into the PPP contract. However, these mechanisms may not be sufficient to deal adequately with some of the changes that may happen during the life of a PPP contract, in particular if more fundamental adjustments are required due to technological disruption. In these cases, a renegotiation of the terms of the long-term PPP contract, i.e., the rewriting of certain parts of the contract, may be the only way to find an adequate solution.

> If more fundamental adjustments to the PPP contract are required to deal with fast-paced advances in technology, a renegotiation of its terms, i.e., the rewriting of certain parts of the contract, may be the only way to find an adequate solution.

Box 11: Renegotiation of the United Kingdom National Air Traffic Services (NATS) PPP after Decline in Demand Due to 9/11 Terrorist Attacks

In the case of the United Kingdom National Air Traffic Services (NATS) PPP, the private partner had agreed to accept all demand risk under the PPP contract. The 9/11 terrorist attacks on the World Trade Center and Pentagon in the United States caused the loss of a large proportion of revenue from North Atlantic traffic. At the same time, total traffic had not declined as a result of the growth of low-cost carriers at the time, which actually increased the operational burden resulting from more landings and takeoffs. Due to these disruptions, the private partner looked certain to default on its debt.

The contracting authority (Board of the Civil Aviation Authority) was split regarding a renegotiation of the PPP contract. The board member directly responsible for the contract insisted the government should not renegotiate, stating the solution was a private sector financial restructuring, in which the lenders to the company would bear some of the losses. The majority of the board disagreed, however, and instead agreed to change the terms of the contract as part of a package deal that also involved debt restructuring and traffic risk-sharing arrangements.

Sources: PPPLRC. "Dealing with Change".
Erhardt, David, and Timothy Irwin. 2004. "Avoiding Customer and Taxpayer Bailouts in Private Infrastructure Projects."
World Bank and PPIAF (Public-Private Infrastructure Advisory Facility). 2010. Investment in Air Transport Infrastructure, Guidance for developing private participation.
(See also "Case Study 5: Portugal – Renegotiation of PPP Highway Contracts after the Global Financial Crisis in 2008.")

Many PPPs are renegotiated. A Global Infrastructure Hub (GIH) study found 48 instances of renegotiation in the 146 projects for which data were available, which roughly equates to one in every three projects. When filtered by region and sector, the study noted a significant prevalence of contract renegotiation in Latin America (58 percent) and in the transport sector (42 percent). In addition, the most common cause of renegotiation was found to be increased costs in construction or operations, and the most common outcome of a renegotiation was a change in tariffs. The timeframe for the study (projects that reached financial close from 2005 through 2015) meant that almost all the projects are still in progress, and therefore may incur further renegotiations in the future.

It is difficult to quantify the number of renegotiations causally related to disruptive innovation. Disruptive innovation is, however, likely to modify projections; to impact project performance and revenue streams across infrastructure sectors; or to require investment in new technology, including AI, big data, or cloud hosting to make the project more digital and efficient. Technological disruption has therefore the potential to increase the number of PPP projects that need to be renegotiated in the future.

With the rapid advancement of renewable energy technology, many governments worldwide are, for example, already considering renegotiating a large number of PPAs with outdated tariff schemes. In addition, renegotiation of PPP contracts may be requested more frequently going forward with regard to PPP urban transportation or parking projects if demand for public transport or parking garages will decline due to an increased use of shared ride systems or autonomous vehicles. With power generation shifting from fossil fuel to renewables, infrastructure assets may also require renegotiation and perhaps even restructuring to convert them to low-carbon use and avoid early shut down, and renegotiation may also be required to adopt new technologies that may be suitable for the particular market. If the contractual mechanisms are not sufficient to deal with the unexpected changes, the question for investors and governments alike is whether the terms of the contract can be renegotiated under the new circumstances.

Renegotiation may sometimes be unavoidable to deal adequately with fast-paced advances in technology that transform long-term PPP infrastructure projects and sectors. Nevertheless, renegotiation should also be avoided to the extent possible. Contracting authorities are subject to public procurement rules that do not give the parties unlimited rights to renegotiate. Fundamental changes of the terms of the contract through renegotiation can undermine competitive and transparent procurement and also lead to opportunistic behavior.[76]

In order to prevent abuses and third-party challenges,[77] renegotiations of PPP contracts are regulated to some extent in most economies. PPP contracts can also include a renegotiation clause. This framework sets out under what conditions renegotiation can be initiated and how any renegotiations should be conducted. Contract managers need to consider in each case the specific PPP contractual and statutory provisions.[78] To prevent abuses, avoid conflict, and ensure buy-in from key stakeholders, PPP renegotiations need to be managed in a strategic and transparent manner and in parallel if several PPP projects are affected.

Once the parties agree to revised terms of a PPP contract, it is recommended that details of renegotiations and circumstances leading to renegotiations are published, including specific changes caused by the renegotiated clauses, e.g., regarding risk allocation as well as roles and responsibilities relating to the project.[79]

[76] One prominent example for an opportunistic renegotiation is the Odebrecht case that took place in Brazil. Although the scandal relied on an elaborate bribery scheme involving public officials and the media, the bribery was also linked to renegotiations. Odebrecht obtained contracts through a competitive process but underbid the contracts, and in at least one case, its bid was below that of the next lowest technically qualified bidder by 25 percent. Once Odebrecht won with a lowball bid and came to commercial close, it was able to renegotiate the contracts because Brazil allows economic rebalancing to manage changes in a PPP contract ("Managing Public-Private Partnership (PPP) Renegotiation" in: Bloomgarden, David. 2020. Enhancing Government Effectiveness and Transparency: The Fight Against Corruption. World Bank Group).

[77] In some civil law countries, renegotiations would generate the need to terminate the contract early and re-tender the project, unless the solution is endorsed by a higher-ranking instrument (such as a decree).

[78] Whether the parties can restructure infrastructure assets under these renegotiation frameworks in a changing technological environment depends on the specific renegotiation framework but is so far not common.

[79] World Bank Group. 2015. A Framework for Disclosure in Public-Private Partnerships.

Considerations for Future PPP Contracts:

PPP contracts should specify under what conditions the renegotiation can be initiated and what the process will be.

The following are examples for best practice PPP contract renegotiation schemes:

- To address lowball bids some countries, such as Colombia and Peru, find it helpful to impose a **moratorium on renegotiation during the first three years of a project.**
- Avoiding opportunism gives justification to requiring **approvals by government agencies other than the procuring authority itself.** This approval process provides more impartial oversight over renegotiations of PPP contracts. Many countries have therefore introduced approval requirements. The South African regulations require, for example the procuring authority to obtain Treasury approval for any material amendment. It also stipulates that the Treasury will approve a material amendment only if it is satisfied that the PPP agreement, if so amended, will continue to provide substantial technical, operational and financial risk transfer to the private party.
- Moreover, contracting entities in the different economies have been regularly instructed to keep contract amendments within certain limits. When renegotiations exceed these **thresholds**, a new tendering process is necessary to support competition. The objective is to ensure value for money for additional works and to give all bidders a level playing field.
- **Modifications that alter the contract substantially** might affect competition and might lead to a breach of procurement law. Therefore, many renegotiation regimes specified in the PPP agreement limit, e.g., changes that affect the risk allocation of the PPP contract as well as other amendments that may be considered a "substantial" change. **In the United Kingdom,** for example, the regulatory framework specifies the conditions under which a change to the contract is deemed "substantial." The general rule is that if substantial modifications are made, a new procurement process may be required.80 However, in cases where the modification results from circumstances that the procuring authority could not have foreseen, does not change the overall nature of the contract, and increases the price by no more than 50 percent of the original contract value, then the modification is not deemed to require a new procurement procedure.

Source: World Bank. 2020. *Benchmarking 2020 Infrastructure Development.*

(ii) Relation management and dispute resolution

Interpretations of PPP contractual provisions, adjustments of contractual obligations, or requests to renegotiate or terminate the PPP contract can be amicable or contentious. The accelerating availability of disruptive technology worldwide will likely result in more conflict between the parties of PPP contracts.

For example, unilateral changes to conditions of PPP contracts by the contractual authority have led to many disputes in the energy sector globally. Generally, courts or arbitration panels will uphold a signed contract. Therefore, a contracting authority that would like to reopen a contract that takes changed technological circumstances into account will be unlikely to succeed through dispute resolution mechanisms and would likely be best served by attempting amicable discussion and negotiation with the counterpart.

> "Contract managers need to consider going forward that disruptive technology may result in more conflict between the parties of PPP contracts. Maintaining an ongoing relationhip between the parties and promoting collaboration between all stakeholders throughout the entire project lifecycle is key to prevent conflicts or their escalation."

[80] See also section 75 Preamble Directive 2014/23/EU of the European Parliament and of the Council of February 26, 2014, on the award of concession contracts which states that "a new concession procedure is required in the case of material changes to the initial concession."

One way to prevent disagreements from escalating is through collaboration of all stakeholders and relationship management over the project's life cycle. Maintaining an ongoing relationship between the parties is therefore key for the prevention of conflicts.

Effective collaboration can be supported by digitization and disruptive technology (see Sections 3.2 and 3.3). If the parties are unable to resolve the situation informally through negotiations, they may want to enter into a formal dispute resolution, resulting in litigation, arbitration or the application of alternative dispute resolution mechanisms. Such mechanisms are typically set out in the PPP contract but can also be contained in statutory provisions, depending on the governing law.

> **Contract managers need to be aware that in the light of disruptive technology it may sometimes make economic sense for the government to terminate the PPP contract unilaterally so that it can upgrade or replace the infrastructure asset, depending on the specific circumstances.**

Dispute resolution provisions in PPP contracts set out a pre-agreed mechanism for the resolution of any disputes that may arise out of the PPP contract. These clauses aim to provide as much certainty as possible about where and how disputes will be resolved and avoid disagreements about where a claim can be heard.

They typically provide a three-staged process:

1. As a first step, the parties typically try to resolve their conflict themselves, through a more formalized **negotiation**. They consult each other for a fixed period of time in order to come to a solution.[81] The contract manager will play a central role during this stage and will manage the communication between the parties. To avoid further conflict, adequate documentation of the agreement that has been reached between the parties is essential.

2. If these consultations fail, the parties may then put their case to **mediation** or to an expert to decide. The expert appointment is regulated by the PPP contract.

3. In case either party is not satisfied with the expert's decision, the dispute is referred either to **arbitration**[82] **or courts**, depending on the PPP contractual provisions.

Conflict management procedures should be invoked as soon as possible after a conflict arises, before it becomes a real dispute or impedes the project. The inclusion of an alternative dispute resolution mechanism, including the use of **dispute review boards**, can be a particularly useful tool to prevent and resolve conflicts arising in the context of disruptive technology because they allow the parties to settle disputes informally at an early stage.

[81] A standard clause on dispute resolution will include a period for amicable resolution of the dispute between the parties through discussions, usually from one to six months.

[82] If the mechanism used is international arbitration, the clause will also state the forum and rules to be used (often the rules of the forum or the International Centre for Settlement of Investment Disputes or International Chamber of Commerce rules). It will specify that the decision of the tribunal shall be final and binding. The clause may also specify the number of arbitrators and how they are to be chosen.

Considerations for Future PPP Contracts:

PPP contracts should contain well-drafted dispute resolution clauses that include:

- The governing law of the PPP contract (if not specified in a different clause).
- An obligation to first discuss the issues amicably and in good faith (possibly through the use of an alternative dispute resolution mechanism, such as mediation or a disputes board).
- A provision for the resolution of specific technical disputes by an independent expert.
- A recourse to either (i) the courts that will have jurisdiction to determine the dispute or (ii) international arbitration to finally determine all disputes not resolved informally or by expert determination. An arbitration clause should specify the "seat" of arbitration and usually also should reference institutional procedural rules. It may also set out certain bespoke procedural rules to govern the arbitration process, and joinder and consolidation provisions in the event the dispute concerns multiple related contracts and/or multiple parties and arbitration has been selected.
- An obligation to continue carrying out the PPP contract during the resolution of the dispute.
- Possibly a waiver of sovereign and other immunities and consent to enforcement and execution.
- Provisions on allocation of costs.

In addition to the informal negotiation provision, contracting authorities should consider including a specific alternative dispute resolution provision. In particular dispute review boards may be helpful to prevent and resolve conflicts arising in the context of disruptive technology. In this case, a respective provision needs to be added to the dispute resolution clause that sets out the requirements for the establishment of a dispute review board and the process to be followed.

Source: World Bank. 2019. *Guidance on PPP Contractual Provisions,* Chapter 11, in particular 11.2.1 and Schedule 1.

(iii) Government step-in rights and emergency clauses

Some PPP contracts provide for governments to "step-in" to the project and take control of the project company (usually in agreement with project lenders), for reasons of national security, health and safety, to discharge a statutory duty, or where the project company is not performing its obligations and the project is delivering an essential service. This should not be confused with a lender's step-in rights to cure a performance breach of the private partner.[83]

Government step-in could take place, for example, if a disruption leads to an emergency situation that prevents the private partner from providing an essential service, e.g., drinking water, electricity or waste management. In the context of disruptive technology this could, for example, be the case if due to a cyber attack, port or airport cargo services get interrupted (essential to keep food and other supply chains open), water supply or power plants are not operating (essential to provide water and electricity), or public transport operators cannot operate (essential workers still need to get to jobs).[84]

[83] World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*

[84] World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*

Generally, the procedure and timeline for step-in, responsibility for costs and liabilities for both parties, and other rights will be set out in further detail in the contract. Whether there will be compensation for the private partner usually depends on whether it is at fault. Some clauses are drafted such that the step-in rights are only triggered where the private partner is not performing, in which case it will not get compensation. Others allow public policy reasons for step-in, in which case some form of compensation to the private partner is usually offered. Either way, the government should only invoke step-in rights if it (or a third-party that it appoints) has the relevant expertise to do a better job than the project company.[85]

For disruptions that lead to emergency situations, some PPP contracts have an emergency services clause that may be triggered in the case of a cyber incident.[86]

Considerations for Future PPP Contracts:

With disruptions likely to continue and a potentially increased number of cyber incidents expected to occur in the future, it will be important for governments to maintain the option of emergency clauses and step-in rights to ensure that essential services continue to be provided to the public despite any disruption. However, governments must ensure that any step-in duration is limited to only the emergency at hand and must be sure to "step-out" of the project as soon as the emergency is over, to restore confidence in the PPP.

(iv) Early termination

If the adverse impacts caused by the disruption continue for an extended period of time, and it is not possible to remedy the scenario or change the contractual relationship in a way that is satisfactory for both parties, one or both parties may wish to terminate the PPP contract. In general, parties of a PPP contract must comply with its terms and cannot simply step away from it entirely on the basis that it is no longer advantageous to continue because technological disruption has dramatically changed the economic conditions.

In some civil and common law jurisdictions, there may be underlying laws addressing certain termination rights and consequences which apply without specific PPP contractual provisions. In practice, however, the parties almost always seek to include express contractual mechanisms in the PPP contract that set out comprehensively what circumstances may give rise to termination, which party may terminate, and what the consequences of termination will be for the contracting authority and the private partner, and for lenders or other key third parties.[87]

[85] World Bank Group. 2021. *Covid-19 and PPPs Practice Note.*

[86] For example, management contracts and operations and maintenance contracts will typically require the operator to develop an emergency management plan, which will have provisions for the operator to take steps in an emergency which is subject to compensation at the cost of the government where such measures are not contemplated in the ordinary course of operations and maintenance (World Bank Group. 2021. *Covid-19 and PPPs Practice Note*.).

[87] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 103.

The ability of parties to terminate a contract will depend on the express terms of the contract. Typical early termination events expressly addressed in PPP contracts are:[88]

- The contracting authority will usually want to protect itself against being tied into a long-term contract which is not being performed to the agreed contractual standard by the private partner **(default by the private partner)**.
- Similarly, the private partner will usually wish to include the express right to terminate the PPP contract itself (and be compensated) for breaches by the contracting authority which have a material adverse effect on the project or the private partner **(default by the contracting authority)**.
- The contracting authority will commonly also seek a right to terminate the PPP contract, at its discretion, for convenience or for public policy reasons **(voluntary decision by the contracting authority)**.[89]
- Both parties will also want to protect against being tied into a long-term contract that is incapable of being fully performed due to a particular occurrence that is typically neither party's fault, and where no solution has been agreed upon in order to continue with the PPP contract **(e.g., due to prolonged occurrence of a force majeure event or unavailability of a key insurance)**.
- A **prolonged change in law/MAGA event** may be treated similarly to a prolonged occurrence of force majeure depending on the specific PPP contractual provisions.[90]

In the event of termination, the government is usually required to compensate the private partner in exchange for the asset. The compensation is typically based on a formula depending on fault:

- If the contracting authority is at fault, then compensation is usually all outstanding debt + costs + forecasted return on equity or some variation thereof. Similar considerations apply usually for voluntary termination, MAGA, change in law.
- If the private partner is at fault, then compensation is usually outstanding debt or market value.
- If the PPP contract is terminated because of a force majeure event, it may be somewhere in between.

In the context of disruptive technology, termination may, for instance, be considered if an infrastructure asset has become obsolete due to technological advancements, such as a fossil fuel plant or a parking garage that cannot be used anymore. In these cases, it may sometimes make economic sense for the government to terminate the PPP contract unilaterally so that it can upgrade or replace the infrastructure asset, depending on the specific circumstances. Unilateral termination can, for instance, make economic sense if the contracting authority can negotiate reduced compensation or has economically attractive options to recycle the asset.

Generally, voluntary termination should, however, only be considered where other PPP contractual provisions or negotiation cannot provide a satisfactory outcome. Together with legal fees for dispute resolution, early termination payments for unilateral termination can entail large fiscal costs for governments. It is therefore usually in each party's best interest to find a negotiated way out of a situation where technological obsolescence or other impacts of disruptive technology justify termination. In practice, where there is a risk of termination, termination provisions are often used to initiate discussions about how to continue the PPP contract or to negotiate a government buyout.

[88] For more details, see: World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 106.

[89] Although unilateral termination rights for the contracting authority typically need to be stated expressly in PPP contracts to be invoked, this is not always the case. In some jurisdictions (typically civil law jurisdictions) the contracting authority maybe entitled to terminate the PPP contract on the grounds of public interest, even without an express contractual right based on underlying national law (World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 107).

[90] World Bank Group. 2019. *Guidance on PPP Contractual Provisions*, p. 53 and p. 68.

Considerations for Future PPP Contracts:

An early termination provision that allows for voluntary termination by the contracting authority adds some flexibility to PPP contracts because it gives a contracting authority the possibility to terminate a contract at its discretion, for convenience, or for public policy reasons. In practice, this solution should, however, only be considered in exceptional cases because it comes with a high price tag for contracting authorities.

Process for Assessing and Resolving Issues related to Disruptive Technology

A. Review of the Project Fundamentals

1. Technological Obsolescence

Have technological standards changed for construction or operation?

Does the integration of disruptive technology require high upfront costs?

Have business models in the sector changed due to disruptive technology?

Has the demand for the service changed due to disruptive technology? Are these likely long term or short term changes?

Have new laws or regulations related to technological standards been put into place?

Cyber Attacks

Has the risk for cyber risk increased?

Have new laws and regulations related to cyber-attacks been put into place?

Is the project affected by cyber attacks?

Data Theft

Has data fraud or theft become a problem?

Have new laws and regulations related to data privacy been put in place?

Economic and Social Disruption

Have disruptive technologies led to economic and social disruption and does this impact the project directly or indirectly?

B. Does the impact lead to financial distress for the project?

Loss of revenue?

Increased costs for construction and/or operation?

Inability of one or both parties to meet obligations?

Risk of obsolescence or of the asset becoming stranded?

C. What contractual provisions are available to deal with these issues?

1. Are there contractual obligations/rights that allow the government to make or request the required adjustments?

- Output-specifications/obligation to operate in accordance with good industry practice?
- Direct contractual obligaton to adopt and/or integrate new technologies?
- Indexing and benchmarking

2. Can the issue be dealt with by changing the term of the contract?

3. Are contractual provisions applicable that permit regular adjustments?

- Variations
- Tariffs/payment rules or formulas

3. Are legal mechanisms applicable to the PPP contract that permit adjustments in exceptional situations?

- Equity principles/restoration of the economic equilibrium
- Force majeure
- MAGA/change in law
- Other compensation and relief events
- Is mandatory insurance covering the risk that has materialized?

4. Can the PPP contract be renegotiated under the contract's renegotiation scheme to deal with the issues?

5. Can the issue be solved through relation management and/or dispute resolution?

6. Are emergency clauses/government step-in rights applicable?

7. Is early termination the only way to deal with the issues caused by disruptive technology?

D. What are potential legal consequences for the government?

Direct obligations and rights under the PPP contract

Direct obligations and rights under applicable law

Potential claims under law and contract

4

Case Studies

4. Case Studies

4.1. Case Study 1: Mongolia – Addressing Disruptive Technology through Renegotiation and Energy Regulation

Background

Mongolia has been exploring renewable energy as a solution to tackle heavy reliance on coal for electricity generation, dependence on imported energy, and increasing energy demand. As of 2018, about 96 percent of the power in the country was generated by coal-fired combined heat and power plants. Mongolia's climate provides great potential for utility-scale solar development. To incentivize this development, Mongolia enacted the Renewable Energy Law in 2007 with an aim to promote green and sustainable energy development in the country. The law mandated a fixed feed-in tariff for electricity generated by renewable energy sources, i.e., wind, hydro and solar power. The law was amended in 2015, mainly to introduce feed-in tariff support for investments made in the renewable energy sector. Further, in June 2015, the Parliament of Mongolia approved the State Policy on Energy, which declared the state's ambition to increase the share of renewable energy to 20 percent in 2020 and 30 percent in 2030.

The generous feed-in tariffs for solar of 2007 (from US$0.15 to US$0.18 per kilowatt-hour (kWh)) incentivized investments in solar. At the same time, they led to capacity oversubscription. In addition, with falling solar prices in global markets and solar energy becoming more and more competitive, the high contracted feed-in tariffs seemed increasingly "out of market." In 2018 the solar power price benchmark was estimated to be from US$0.0645 to US$0.0813. In 2018 the government of Mongolia recognized that a reform of the renewable energy regulatory framework was necessary, especially for solar power price setting.

The Energy Sector Management Assistance Program (ESMAP), a multi-donor technical assistance trust fund administered by the World Bank, provided funding for this technical assistance (TA) to Mongolia. The TA's objective was to provide advisory services to the Energy Regulatory Commission (ERC) to set a sustainable solar power price and create a strategy for revision of the contractual terms with some of the solar power special permission holders. The recommendations are summarized in the report *Support Mongolia with Solar Energy Price Setting* of 2018.

PPP Projects

Between 2013 and 2017 the Energy Regulatory Commission (ERC) of Mongolia granted 29 special permissions for solar PV projects. As of October 2018, these fell into three different groups according to their development stage:

- **Projects in operation:** Two solar PV power plants were commissioned in 2017 for a term of 20 years. They had a total capacity of 20 megawatts (MW) and an average tariff of US$0.16 per kWh.
- **Projects in construction:** Three projects were planned and constructed in 2018 and 2019. They had valid licenses and interconnection permits, a total capacity of 40 MW and an average price of US$0.16 per kWh. The PPA terms were from 10 to 15 years.
- **Projects in preparation:** Several projects had obtained all licenses, but they were not able to proceed to construction quickly. This included four solar PV plants with a capacity of 99 MW with licenses expiring between November 2018 and May 2021.

Overall, the terms for these PPAs (10 to 20 years) were shorter than the international average for solar PPAs. The PPAs did not include adjustment mechanisms.

The report *Support Mongolia with Solar Energy Price Setting* recommended the following for reduction of solar power tariffs:

- **Renegotiation** of the terms of the PPAs intended to give benefits to special permission holders so that they would be incentivized to accept a lower PPA price. As "sweeteners" the report proposed the following:
  - **Extended PPA length:** A longer PPA term would allow developers to recover the initial investments and achieve the targeted rate of return later, which would make the lower price more appealing.
  - **Escalated PPA price** by an agreed rate, e.g., 3 percent.
  - **Refinancing** accompanied with better lending terms such as lower interest rate (or language in the PPA allowing its use as collateral in the event of project refinancing).
- With prices for renewables continuing to decline, it was also recommended that Mongolia **switch from fixed feed-in tariffs** as a price setting mechanism for solar power to auctions as a price setting mechanism. Although auctions can lead to higher transaction costs and more time-consuming administrative procedures, it was expected that they would allow for competition and drive down the PPA price for renewable power.

The parties entered into a constructive process to solve the issues around the PPAs and established a working group. A renegotiation of the tariffs was, however, not attractive for the private sector parties because the expected loss of revenues was a serious concern for lenders.

In 2019, Mongolia amended the Renewable Energy Law. The high feed-in tariff was abandoned and instead, a cap of US$0.08 per kWh was introduced for solar power to reflect current market conditions. In addition, the government introduced auctions as an additional procurement method for renewable energy development. The model PPA for future solar contracts will deal with some of the issues that have surfaced in relation to the first PPAs for renewable energy deployment.

Lessons Learned

Renegotiation of tariffs in PPAs caused by disruptive technology can be difficult if they impact return expectations of investors.

- If issues arise due to unexpected changes of circumstances related to disruptive technology, it can be helpful if all project partners collaborate to find a solution.
- Broader issues that arise in connection with new technological developments and affect a number of contracts can be addressed through regulatory reforms for future contracts, e.g., a switch from high feed-in tariffs to a ceiling for tariffs combined with a parallel auction system.
- Incentives to adopt new technologies—such as feed-in tariffs—should be applied cautiously and in a gradual way to ensure that the government does not overcommit unnecessarily.

Source: World Bank and ESMAP (Energy Sector Management Assistance Program). 2018.
Support Mongolia with Solar Energy Price Setting: Final Report.

4.2. Case Study 2: Australia – Considering Future Technology Improvements to Victoria Water Desalination Plant

Background

After a decade that saw major droughts in the Australian state of Victoria's central and eastern regions, including Melbourne and Geelong, desalination had become crucial for the water supply in the area. Melbourne's freshwater storage reserves dropped from nearly full capacity in 1996 to less than 30 percent in 2007. Against this background, the Victoria State Government announced the procurement of the Victoria Desalination Plant to ensure Melbourne's and regional Victoria's urban water supply was not rainfall dependent and could better withstand the effects of climate change.

The Victorian Desalination Project is located in the Wonthaggi region. The plant is one of the world's largest and most energy-efficient reverse osmosis desalination plants. It is capable of supplying up to 150 billion gigaliters of water a year to Melbourne, Geelong and, via other connections, South Gippsland and Western Port towns. The project design also allows for a possible capacity expansion to up to 200 billion gigaliters. The project is being delivered as a PPP project by the AquaSure consortium. It reached financial close on September 2, 2009, and achieved final commissioning completion on December 17, 2012.

PPP Project

AquaSure entered into a 30-year PPP contract with the Victoria State Government in 2009 to design, construct, operate and maintain the desalination plant and the associated infrastructure. The private partner delivers desalinated water to state-owned water authorities, which in turn deliver this water to households. The scope of the project includes: the construction and operation of the desalination plant, the 84 kilometer (km) transfer pipeline to connect to Melbourne's existing water supplies, delivery of power supply for the project, operations and maintenance, and the purchase of renewable energy credits.

The project considers the latest technology, such as leading-edge technology and practices for membrane efficiency and energy efficiency. The PPP contract also takes future technology improvement into account, and acknowledges that there will be advances in the technology used in desalination plants (for example, new, more efficient membrane models). It is also anticipated that significant benefits may be achieved by upgrading the desalination plant and associated infrastructure to utilize new technology (both in terms of cost savings and efficiency or environmental benefits) and that there will also be costs associated with implementing the new technology.

The PPP contract balances these considerations to achieve the best value for money outcome, while retaining flexibility for the private partner and the contracting authority to weigh the costs and benefits of new technology on a case-by case basis: The private partner must maintain a level of technology in the desalination plant and associated infrastructure that is consistent with best industry practice and ensure that the system is able to operate effectively and efficiently with the Victorian water and electricity networks. Technology upgrades beyond this standard can be initiated by either party. If the contracting authority proposes a technological upgrade, it will pay for the modification (unless otherwise agreed with the private partner). The contracting authority will retain the whole benefit of any cost savings resulting from the modification. Alternatively, if the private partner proposes and implements new technology, this can only be done with the contracting authority's approval. Any cost savings resulting from the new technology will be shared by the private partner and the contracting authority.

Lessons Learned

The PPP contract considers future technology improvement. As is common for projects that depend on the latest technology, the PPP contract obliges the private party to ensure that the level of technology is consistent with best industry practice. It allows both parties to initiate variations related to new technology. The PPP contract provides an interesting incentive for the private partner to identify and propose technical innovations which reduce the overall costs of the project and enhance efficiency by ensuring that the parties benefit equally from cost savings achieved as a result of the implementation of new technology initiated by the private partner. If the contracting authority proposes new technology, it pays for the upgrade but also receives the whole benefit of any cost savings.

Sources: Victoria State Government. *Victorian Desalination Plant.*
Porter, Kiel. 2010. "Victorian Desalination PPP." *Project Finance & Infrastructure Journal.*

4.3. Case Study 3: United States, Maryland – I-495 and I-270 PPP Project

Background

For decades, congestion has plagued travelers on the Maryland side of the Capital Beltway (I-495) and I-270. In 2017 the governor of Maryland announced Maryland's Traffic Relief Plan to reduce traffic congestion, increase economic development, enhance safety, and return quality of life to commuters. The plan proposed replacement of the American Legion Bridge and addition of four **new "high-occupancy toll" (HOT) lanes** to portions of the I-495 and the I-270. The plan was designated as eligible for public-private partnership (PPP) projects. Once completed, the project will be the largest highway PPP of its kind in the world. It includes over 70 miles of existing interstate highway extending along I-495 and I-270 and will be developed and delivered pursuant to the following overarching goals: **congestion relief,** impact minimization, no net cost to the state, accelerated delivery, and significant **innovation.**

PPP Project

The procuring authorities are the Maryland Department of Transportation (DTOT) and the Maryland Transport Authority (MTA). They will jointly deliver the I-495 and I-270 PPP project. The project is divided into three phases that represent sections of the project. The first section encompasses work for I-495 from the vicinity of the George Washington Memorial Parkway in Virginia, across and including the American Legion Bridge to its interchange with I-270, and for I-270 from its interchange with I-495 to its interchange with I-70 (phase 1).

Different from other PPPs that have so far been delivered in Maryland, the project will be developed and delivered using a multi-step progressive PPP approach for each section. The selected bidder will first enter into a **phase PPP agreement** and collaborate directly with the relevant agencies and stakeholders on predevelopment work. This upfront effort will focus on advancing the preliminary design and due diligence activities for the project by involving all stakeholders—including affected counties, municipalities, property owners, utilities, and citizens. Afterwards the procuring authority intends to move forward with a **section PPP agreement** under which a subsidiary of the phase developer will be responsible for the section work, i.e., the final design, construction, financing, operations and maintenance of a section for a term of 50 years.

The procuring authorities issued a request for proposal (RFP) for phase 1 in February 2020. Qualified respondents were then invited to submit a proposal to assist in the predevelopment work and enter into the phase PPP agreement for the project in July 2020. The procuring authorities have incorporated an unusual **dialogue process** to **foster creativity and innovation** in the development and delivery of phase 1 of the project. This process allows bidders to deviate from the RFP documents and to introduce innovative technical or financial solutions.

On February 18, 2021, the Maryland Department of Transportation (DTOT) and the Maryland Transportation Authority (MTA) chose the consortium Accelerate Maryland Partners LLC (AMP) to handle the first phase. The consortium includes Transurban and Macquarie Infrastructure Developments as lead equity developers and lead contractors. To make the project more sustainable, efficient and accessible for communities through technology, AMP added strategic partners to the team, e.g., an **innovative transit company** as well as a transportation technology start-up for **digital innovation** that aims to build the future of roads "alongside strong government and industry partners for the acceleration of autonomous and connected vehicles" providing "digitally advanced road technology that is designed to be safer, less congested, more efficient in the movement of goods, and improve access to public transit."

Lessons Learned

Where new and unknown technologies are involved, a two-stage procurement process together with an innovative dialogue process could prove critical to finding the most qualified PPP team and to enhancing the probability of success. Likewise, early robust and comprehensive public engagement with key stakeholders (including affected counties, municipalities, property owners, utilities, and citizens) perhaps using a progressive model, can foster a collaborative and transparent process, advance the preliminary design and due diligence activities, and, it is hoped, will in turn lead to more resilient projects for the community and the project sponsor.

Sources: Maryland Department of Transportation and Maryland Transportation Authority. 2021. *A Report to the Maryland General Assembly, Senate Budget and Taxation Committee, and House Appropriations Committee, House Ways and Means Committee Regarding Phase 1 of the I-495 and I-270 Public-Private Partnership (P3) Program.*

Maryland Department of Transportation and Maryland Transportation Authority. 2020. *Request for Proposals for Phase 1 of the I-495 & I-270 Public-Private Partnership Program through a Phase Public-Private Partnership Agreement among the Maryland Transportation Authority and the Maryland Department of Transportation, including the State Highway Administration*. July 24, 2020.

Maryland Department of Transportation and Maryland Transportation Authority. 2021. Annual Report to the Maryland General Assembly regarding Public Private Partnerships.

4.4. Case Study 4: Portugal – Renegotiation of PPP Highway Contracts after Global Financial Crisis

Background

Portugal started implementing a large PPP program in 1993, in particular in the transport and health sectors. Under its PPP program the country has approved a high number of PPPs over a short period of time. From 1995 to 2014, a total of 35 PPP projects were launched with future annual government obligations accounting for more than 0.5 percent of GDP. (A proper government control or an appropriate accounting and reporting system was not yet in place at this time.) The financial crisis of 2008 led to a broader economic crisis and recession that impacted capital flows and trade in many countries. It devastated Portugal's economy and also had a critical impact on the country's transport sector. Port and road infrastructure as well as the shipping industry were significantly impacted by the reduction in global trade. In the wake of this difficult economic environment, some of Portugal's PPP contracts became an unbearable financial burden for the government.

PPP Projects

In the transport sector the Portuguese government had procured a large number of PPPs to develop and manage its national highway system. Many PPP highway projects used "shadow tolls" that the government paid to the private partner per user with a high guaranteed minimum revenue. With the onset of the economic crisis, the PPP highway contracts caused unexpected and considerable stress on public finances. In the wake of this crisis the government initiated renegotiations with the respective private partners. A renegotiation of the PPP highway contracts was also one condition for financial assistance from the European Commission (EC), European Central Bank (ECB) and International Monetary Fund (IMF) that Portugal had requested. Because the PPPs were viewed as a key driver of Portugal's unsustainable fiscal situation, the bailout package required that the Portuguese government would review its PPP program, suspend all new PPP agreements, and renegotiate some PPP contracts to reduce the financial burden caused by their current and anticipated payments.

Systematic renegotiation of the PPP highway contracts led to an overall reduction of public payments, reducing internal rates of return (IRRs) by cuts in payments for capital expenditures (CAPEX) and operating expenses (OPEX). The government was able to reduce current and future payments under each PPP by an average of 18 percent, rendering the PPPs sustainable and profitable. It had to accept that the terms of the PPP contracts it had originally agreed to were based on incorrect traffic projections and were not sustainable. Because the overall costs of the projects were lowered, the private partners also saved some costs. Shadow toll roads were converted into real toll roads with traffic risk borne by the government.

Lessons Learned

A renegotiation of several PPP contracts on the initiative of the contracting authority can be unavoidable if the need to restructure PPP contracts becomes apparent as conditions change. Full cooperation of all public and private sector partners and stakeholders and simultaneous renegotiations for all affected contracts are required to enhance transparency and sustainable outcomes in these cases. In the case of Portugal's PPPs, the government was able to achieve its goal to reduce the costs for the contracts because the private sector' s perspective was also taken into account. Although their returns were lowered, the outcome was on balance acceptable for the private sector partners given the lower risk profile and cost savings. Buy-in from the private sector was facilitated by the fact that the Portuguese government was in a distressed economic situation, and the restructuring of the PPP contracts helped to prevent bankruptcy of the contracting authority that would have ensued in default scenarios.

Sources: EPEC (European PPP Expertise Centre). 2014. Portugal PPP Units and Related Institutional Framework.

"OECD. 2015. Public Private Partnerships for Transport Infrastructure - Renegotiations, How to Approach Them and Economic Outcomes, Roundtable Summary and Conclusions," Discussion Paper No. 2014-25.

Makovsek, Hasselgren, and Perkins. 2015. Bringing PPP into the Sunlight – Synergies Now and Pitfalls Later? International Transport Forum (ITF), February 2015.

4.5. Case Study 5: Puerto Rico — Technological Upgrades and Contract Extension for P-22 and P-5 Toll Roads

Background

Puerto Rico Highway 22 (PR-22) and Puerto Rico Highway 5 (PR-5) are limited access toll highways serving Puerto Rico's northern coast and the San Juan metropolitan area. PR-22 is a 52-mile, four- and six-lane highway with seven toll plazas, which stretches westward from San Juan to Hatillo. It is the most heavily travelled highway in Puerto Rico. PR-5 is a 2.5-mile eastward extension of PR-22 (the facility is four miles in total) to Bayamón (Puerto Rico's second largest city), where its single toll plaza is located, and which opened in 2006.

Both roads were leased in 2011 to a concessionaire that will rehabilitate, operate and maintain the toll roads over a 40-year period, which was later extended to a 50-year term. The concession agreement was signed on June 27, 2011.

PPP Project

The project was initially structured as a 40-year lease concession agreement for the maintenance and operation of the two highways, PR-22 and PR-5. The contracting authority (Puerto Rico Highway and Transportation Authority) transfers responsibility for operation and maintenance, including related capital improvements and investments, to the private operator (Autopistas Metropolitanas de Puerto Rico LLC) during the term of the contract. Asset ownership remains with the public partner and possession reverts at the end of the concession period. The private partner recovers its investment from revenues directly paid by end-users. At the time of the concession agreement's execution, PR-22 and PR-5 were in substandard condition. The toll roads required new pavement, signage, lighting, and safety barriers in order to improve traffic service and safety.

The private partner had to make an upfront payment to the contracting authority of US$1.08 billion (of which about 90 percent—US$902 million—was used to defease all outstanding tax-exempt toll-revenue debt) and committed to make certain investments to upgrade the toll roads. The private partner agreed to implement a group of improvements in the first three years of the lease period to address safety and quality. Those improvements cost roughly US$50 million, whereas an additional US$300 million in investment is planned over the lease period.

Under the contract the private partner was obligated to construct two reversible, dynamically priced toll lanes in the medians of PR-22 and PR-5 from Toa Baja to Bayamón (approximately six miles). The new lanes increase the free flow of traffic in and out of Bayamón and provide new public transit options for commuters. In addition to bus rapid transit, the lanes allow motorists paying a premium rate to use the lanes to avoid congestion. Toll rates vary in real time to meter the amount of paying traffic and ensure congestion-free conditions. The reversible dynamic toll lanes were opened in August 2013.

All initial improvements were carried out over a period of four years. After negotiations with the PPP unit, the concession agreement was amended on April 21, 2016. The private partner agreed to make additional investments for the implementation and operation of new tolling gantries that allowed for the implementation of new technology, e.g., bi-directional operation of certain sections of the PR-22 and PR-5 highways. The contract was extended by 10 years in exchange for an additional payment from the concessionaire to the project sponsors of US$115 million. In order to cover additional costs incurred, the concessionaire's revenue share was increased from 50 percent to 75 percent of future toll revenues.

Lessons Learned

Transparency throughout the entire procurement process with the PPP unit facilitated a strong partnership with all parties, including government agencies, investors, developers, and public interest groups. Flexibility of the contractual terms was achieved through competent PPP contract management by the PPP unit (Puerto Rico PPP Authority). Technological changes that made an adjustment of the contractual terms necessary represented a good example of the latest innovations in road projects and improved the levels of service. The renegotiation took place under the supervision of the PPP unit, which had the required expertise and managed the contract renegotiations with a view to guaranteeing that the changes were beneficial for all parties involved.

Sources: U.S. Department of Transportation, Federal Highway Administration. *Project Profile: Puerto Rico PR-22 and PR-5 Lease.*

M. Figueroa and A. Pérez-Rentas, DLA Piper. 2017. *Public-Private Partnerships in Puerto Rico, Key Points.*

5

Conclusion and Next Steps

5. Conclusion and Next Steps

Technology is consistently innovating and developing. However, during recent years the pace of technological change has been accelerating rapidly across the global economy. Disruptive technologies can open up unprecedented opportunities for all infrastructure sectors, in particular with regard to digitalization and decarbonization. At the same time, innovative technology has the potential to displace established business models or supersede existing technologies within a short timeframe, thereby creating winners and losers within infrastructure markets.

Against this background, governments increasingly face challenges caused by disruptive technology when managing long-term PPP contracts. Strategies that have allowed governments to overcome these challenges and to enhance "innovation resilience" and facilitate the adoption of disruptive technology are:

- Plan for innovation
  - **Output specifications:**
    - Anticipate long-term needs.
    - Quantify innovative technology risk (caps and exceptions).
  - **Variations:**
    - Allow for technology changes if compensated.
    - Consider risk sharing for unpredictable technology changes (e.g., risk of obsolescence or upgrades with major cost implications).
    - Integrate gain sharing mechanism to incentivize the adoption of superior technology.
- Enhance flexibility
  - **Equity principles:**
    - Integrate explicit provisions that restore balance of economic equilibrium where mandated.
    - Consider integration of equity principles where possible (subject to legal advice).
  - **Term:** Enhance flexibility related to contract term, e.g., present value-of-revenue (PVR) contracts.
  - **Change in law:**
    - Limit/share risk for laws/regulations that require technical enhancement unless the requested upgrade is affecting the general economy and any type of business.
    - Integrate financial relief mechanisms to share and limit cost impact if legal obligation was not foreseeable and adversely impacts in a material form economic equilibrium of contract.
- Consider potential cyber attacks
  - Consider risk of cyber attacks when drafting force majeure/MAGA clauses.
  - Consider availability of insurance for cyber risk (mandatory insurance requirement?).

- **Promote strong partnerships and contract management before dispute stage**
  - Cultivate strong relationships with the partner and stakeholders, to find amicable solutions when things change, before the disputes stage.
  - Alternative dispute resolution mechanism in PPP contracts, including the use of dispute review boards, may be useful to prevent and resolve disputes.
- **Consider renegotiation and termination**
  - Consider renegotiation/termination where technological disruption has fundamentally altered circumstances long term.
  - Specify process and conditions for renegotiation in PPP contract.
  - Include provisions that give contracting authority the right to voluntary termination.

To increase the resilience of PPP contracts going forward and to encourage and facilitate the implementation of disruptive technologies with regard to future PPP contracts, governments need to prepare for technological disruption before the PPP contract stage. The following strategies could be applied going forward:

- **Plan for disruptive innovation**
  - Identify, assess and allocate risks/opportunities associated with potential technological changes.
  - Find possibilities to integrate new technologies into projects throughout all stages.
- **Incentivize flexible and innovative solutions during procurement**
  - Consider quality of technical solution and its flexibility to adapt to a changing technological landscape during PPP procurement.
  - Focus, e.g., on life-cycle costs and collaborative procurement methods that allow bidders to prepare alternative proposals or to propose innovative solutions.
- **Focus on climate-smart and digital projects**
  - Prioritize "green" and digital infrastructure projects (including smart-city components).
  - Set out low-carbon and digital targets.
- **Collaborate with all stakeholders** throughout project development to identify and adopt innovation (e.g., give access to data).

This report provides guidance to developing country governments on managing PPP contracts in the face of innovative technologies. It attempted to create a framework for thinking about potential strategies to enhance resilience and flexibility of PPP contracts in the face of disruptive innovation.

The examples, case studies and recent reports reviewed with regard to disruptive technology and disruptive events provided crucial inputs for the development of this framework. These inputs made it possible to highlight several strategies that governments could consider to make PPP contracts and contract management fit for the Fourth Industrial Revolution.

However, this report can only be a starting point—given the various types of disruptive technology that could impact infrastructure projects going forward and the fact that these technologies can be integrated into the physical infrastructure as well as used in infrastructure design, planning, delivery and management, and can affect PPP projects and their partners in a number of different ways as well as sector-specific differences. Because disruptive innovation as well as disruptive events are continuing to change infrastructure markets globally, it is expected that the evidence base for this report can continuously be expanded in coming years to make the analysis and guidance even more robust.

Appendixes

Appendixes

Appendix A: Examples of Disruptive Technologies and their Applications to Infrastructure

The following is a non-exhaustive list of disruptive technologies and their impact on PPP infrastructure projects:

Renewable energy

- **Generic description:** Renewable energy refers to the generation of energy through renewable resources, such as solar, wind, water, geothermal or biomass. Advances in renewable energy technology, including solar PV panels and battery storage technology, together with a strong policy push in this direction, have made renewable energy technology a disruptive technology for conventional fossil fuel-based power generation.

- **Application to infrastructure:** The power sector has seen significant transformation towards renewable energy and away from fossil fuels, with substantial cost decreases for solar and wind. Electrification with renewables is also underway in the transportation sector and already a viable option for rail and road transport. Renewables are also used to power **smart cities.** For more on renewables, see "Appendix B: Disruptive Technology in the Energy Sector."

Stationary and mobile energy storage devices

- **Generic description:** Stationary and mobile energy storage refers to devices or systems that store energy for later use, including batteries. In recent years storage technology has advanced and prices have steadily fallen.

- Improvements in **lithium-ion battery** technology and materials, particularly improving sustainability, have resulted in increases in battery life, storage capacity, and production. Because of these innovations, the cost of lithium-ion battery storage has dropped almost US$1,000 per kWh in the last 10 years.[91] **Green hydrogen** has also become an important option for the storage of excess energy from renewable energy sources. Green hydrogen is hydrogen that is produced by electrolysis using electricity from renewable energy resources. The hydrogen can be stored and eventually re-electrified via fuel cells. The efficiency of this process today is as low as 30 percent to 40 percent, but it could increase if more efficient technologies are developed. Demand for hydrogen continues to grow due to much longer discharge duration and higher power capacity when compared to lithium-ion batteries (small-scale storage) or to pumped hydro and compressed air energy storage (large-scale storage).[92]

[91] BloombergNEF. 2022. *Race to Net Zero: The Pressures of the Battery Boom in Five Charts.* According to the BloombergNEF report, prices are edging ever closer to the US$100-per-kilowatt-hour mark at which EVs are expected to reach parity with internal combustion engine vehicles on an upfront cost basis. However, amid rising raw material and component costs, battery prices could increase for the first time since at least 2010 and climb to US$135 per kilowatt-hour in 2022, some 2 percent higher than a year earlier.

[92] Twinn, Ian. 2019. "Innovations in Transport." In *Reinventing Business through Disruptive Technology.* Washington, DC: International Finance Corporation.

- **Application to infrastructure:** The transportation sector has spearheaded innovations in mobile energy storage systems, with the most used storage technology being lithium-ion batteries used to power electric vehicles. Lower-cost batteries and the continued optimization of battery technology have already prompted a high demand for electrical vehicles (EVs) and hybrid electrical vehicles (HEVs), which are also creating demand for new charging infrastructure that needs to be integrated into transportation networks. Other innovative infrastructure solutions, such as trains that run on roads and rails, also rely on battery technology for electrification. In the Netherlands the first passenger train powered by a hydrogen fuel cell, which produces electrical power for traction, was tested in 2020.[93] In the energy sector, lithium-ion batteries have become viable for in-home, behind-the-meter, and other localized energy storage, but most notably, have become important for stationary utility-scale renewable energy storage systems. Mini grids that use hydrogen as a complement to batteries are currently being tested.[94] For the energy sector this means that renewable energy sources, such as wind and solar that are weather dependent, can now be made available any time. In addition, the deployment of innovative stationary utility-scale, front-of-the-meter energy storage systems is on the rise, adding flexibility and reliability to electrical grids.

Mobile internet (MI)

- **Generic description:** The term "mobile internet" refers to the ability of mobile devices, such as tablets and smartphones, to connect to the internet. Mobile devices are becoming increasingly inexpensive, powerful and capable, while high-speed wireless networks advance rapidly. One recent technological advancement is the development of 5G, the fifth generation mobile network. With high bandwidth and real-time data transfer capabilities, 5G will dramatically enhance remote use applications.

- **Application to infrastructure:** Parallel with the development of AI, machine learning, the IoT, and blockchain (see below), innovations in fiber optics and 5G technology have greatly increased download and upload speeds, and have enhanced reliability, capacity, and accessibility. High bandwidth and low latency from 5G will improve data capture and data access across project delivery processes. Sharing large amounts of data, including visual data, in real time will enhance transparency, informed decision-making, and data analysis.[95] It also will make building information modeling (BIM) technology possible, allowing developers to create data-based, digital 3D models of projects so that architects, engineers, and contractors can simultaneously collaborate. In the transport sector, 5G will facilitate vehicle-to-vehicle communication and vehicle-to-traffic-controller communication going forward. **Smart cities** are based on high-speed wireless networks together with IoT and AI solutions to manage and govern **municipal water and waste management, electricity generation**, and **street lighting**.

[93] ENGIE. 2020. "ENGIE successfully refuels the world's first renewable hydrogen passenger train in test in the Netherlands." ENGIE (press release), March 13, 2020. (Last visited: September 13, 2022.) .

[94] Silverstein, K. 2020. "Hydrogen May Be The Crucial 'Jigsaw' Piece For Green Microgrids." *Forbes*, July 12, 2020.

[95] KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

Artificial intelligence (AI)

- **Generic description:** AI refers to computer science that enables machines to function in ways usually associated with the human brain so that they can learn, process data, predict, problem-solve, and make decisions. According to the American scientist Marvin Lee Minsky, the father of AI, it is "an application capable of processing tasks that are currently performed more satisfactorily by human beings insofar as they involve high-level mental processes such as perceptual learning, memory organization and critical thinking."[96] Machine learning (ML) is a subcategory of AI that allows a machine to learn on its own through experience and without human intervention.

- **Application to infrastructure:** ML is also used in many **autonomous and semi-autonomous** devices, like drones, autonomous vehicles and artificially intelligent robots. The sensors on these devices relay real-time data, and ML enables the device to make a decision based on that data. For example, when an autonomous vehicle approaches a pedestrian, the sensors detect and relay the data, ML processes the information and makes a decision, and then the control system performs the decided action, i.e., to stop or swerve the vehicle.

- **Pilotless drones** can be used to collect visual data, e.g., for urban air-traffic control to manage the flow of vehicles, or geo-spatial data for environmental and social assessments. Drones are also increasingly used in the freight and logistics industry. They can, for instance, be used to transport goods to or from isolated areas or to overcome the issue of last-mile delivery, which many logistics operators face in areas where road networks are either underdeveloped or poorly maintained. Future unmanned cargo planes will be large enough to carry hundreds of pounds of goods across hundreds of kilometers, with the potential to replace cargo airplanes and even shipping vessels in some scenarios.[97] As the technology progresses, road traffic may decline as fewer delivery trucks are needed. Another potential application of drones is for use as so-called air taxis.

- **Autonomous vehicles** are likely to revolutionize passenger and freight transportation. A system of AVs, coordinating with each other and with a traffic controller algorithm, could increase lane capacity and dramatically reduce traffic time, congestion and energy use, thus making freight and passenger traffic on the road or urban transport systems more efficient. Due to their specific operating requirement, AVs will, however, need an entirely different transport infrastructure than conventional vehicles. Going forward, road, bridge and tunnel infrastructure may increasingly need to integrate sensing technology for AVs. EVs, on the other hand, will make some existing transport infrastructure—such as fueling stations—obsolete, as well as disrupt the market for conventional automobiles.

- Finally, AI and ML can be used for **preparing, designing, constructing and operating infrastructure assets**. In the preparation stage, AI, together with big data and the mobile internet, can, for example, connect team members with real-time visual data, and will likely lead to faster and more informed decision-making. During construction, mini robots can help track work as it progresses. AI may be used to design the routing of electrical and plumbing systems, and develop safety systems at work sites in order to reduce accidents and safety hazards. In addition, AI is already used to pursue real-time interactions of machinery, workers, and objects on site, and alert supervisors of potential safety issues, productivity issues, and construction errors. It may thus lower the frequency of expensive errors, reduce the number of worksite injuries, and make building operations more productive.[98]

[96] Enkronos. 2020. "Artificial Intelligence: Definition, Advice, Comparisons, Testimonials…" *Enkronos* (blog), November 18, 2020. (Last visited September 13, 2022.)

[97] Global Infrastructure Hub. 2020. *Unmanned Aerial Vehicles for Freight and Logistics*.

[98] GlobeNewswire. 2019. "Artificial Intelligence (AI) in Construction Market to Reach USD 4.51 Billion By 2026." GlobeNewswire; KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

Mixed reality (MR), virtual reality (VR), and augmented reality (AR)

- **Generic description:** Virtual reality (VR) refers to a technology that replaces the reality with a simulated digital 3D environment, where the user is fully immersed in the virtual world. The user can look and move around the artificial environment and interact with its virtual features.[99] Augmented reality (AR) supplements the physical real-world environment through the addition of more data by audio, visual, or other means. AR can be defined as a live, direct or indirect view of a physical, real-world environment whose elements are augmented or overlaid by computer-generated sensory input such as sound, video, graphics or GPS data.[100] Whereas VR replaces the real-world environment, AR alters the user's perception of the real world environment. AR and VR are both part of a wider field of technology called mixed reality (MR). MR describes different technologies that can blend the physical world with the digital world.[101]

- **Application to infrastructure:** MR technologies can be integrated in all stages of infrastructure planning, design and implementation.[102] They can, for instance, help to create immersive experiences that show how the new or upgraded infrastructure asset will look and how the design will interact with and impact the existing environment. MR thus can give insight into potential design flaws, risks, and other concerns during the infrastructure planning stage as well as during construction and operations.

Big data

- **Generic description:** The term "big data" describes the high volume of complex digital data requiring the use of advanced analytics for processing. This has meant discovering new orders of magnitude in the capture, retrieval, sharing, storage, analysis, and presentation of data. Thus, the term "big data" refers to the storing of huge amounts of information on a numerical basis.

- **Application to infrastructure:** Big data and analytics will influence how we design infrastructure. Building information modeling (BIM) is already used for 3D modeling in the design and construction phase, so that architects, engineers, and contractors can simultaneously collaborate. This allows those who design infrastructure to provide real-time support to those building it. Advances in BIM technology will also increasingly provide insights into how a project will perform throughout its life cycle, allowing a view into a project's future risk profile. Big data solutions also enable real-time collection of data from infrastructure asset operations, with a wide range of applications for the construction, management, financing, maintenance and operating of assets. Big data from weather, traffic, and community and business activity can be analyzed to determine optimal phasing of construction activities. Geolocation of equipment also allows logistics to be improved, spare parts to be made available when needed, and downtime to be avoided. During operation, big data from sensors built into structures can monitor performance. This means, for example, that energy conservation in buildings can be tracked to ensure it conforms to design goals. Traffic stress information and levels of flexing in bridges can be recorded to detect any out-of-bounds events. Data can also be fed back into BIM systems to schedule maintenance activities as required.[103]

[99] Global Infrastructure Hub. 2020. *Virtual and Augmented Reality for Planning and Design.*

[100] GlobalData Energy. 2019. "Why augmented reality will increase safety and efficiency in utility sector." GlobalData Energy (comment), April 24, 2019. (Last visited September 13, 2022.)

[101] GIH (Global Infrastructure Hub). 2020. *Virtual and Augmented Reality for Planning and Design.*

[102] GIH (Global Infrastructure Hub). 2020. *Virtual and Augmented Reality for Planning and Design.*

[103] Burger, Rachel. 2019. "How the Construction Industry Is Using Big Data." *LiveAbout*, February 3, 2019; KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020.

Blockchain

- **Generic description:** Blockchain technology offers transparent and up-to-date verifiable transactions without the need for intermediaries. Blockchains are unique identifiable blocks (ledgers) of data organized in chronological transaction chains, with each new block referencing the previous block. They are decentralized and distributed on peer-to-peer networks. Generic blockchain technology was developed with the idea that the network would be permissionless and have open access for anyone to become a participant.

- **Application to infrastructure:** Blockchain applications in infrastructure include everything from crowdfunding of power projects to enabling flexi-grid systems, interoperability applications for transportation mobility, and improving supply chain and logistics records.[104] The ports of Antwerp, Rotterdam, and Singapore have, for example, already employed blockchain technology programs to improve port efficiency. Blockchain technology can also be incorporated into the bidding and contracting process. A smart contact uses this technology to automatically execute an agreement when predefined conditions are met. Blockchain and the different mechanisms it enables thus have the power to increase transparency and predictability, reduce the risk for conflict and disputes, and make contract management more efficient.[105]

Robotics

- **Generic description:** Robotics refers to a technology designed for automating repetitive tasks. This technology is often based on the use of AI software or ML that makes "software robots" capable of imitating a human worker. The software robot connects to an application to manipulate data, perform calculations, communicate with other digital systems, or carry out various actions. For example, it may perform database inquiries, maintain records, or process transactions.

- **Application to infrastructure:** Existing robotic technologies deployed in construction, such as motion control, navigation, and computer vision, are expected to be augmented with complex physical and cognitive tasks in both the construction and operation of infrastructure assets. There are construction robots for bricklaying and masonry, and robots that lay an entire street at once, dramatically improving the speed and quality of construction work. Demolition robots may be slower than demolition crews, but they are safer and cheaper.

Internet of things (IoT)

- **Generic description: The term IoT is used to refer to a system in which physical objects are connected to the internet and capable of creating, collecting, and exchanging data in real time in order to create value for its users. IoT systems often use embedded sensors and are controlled remotely. For example, thermostats, cars, lights, and refrigerators can all be connected to the IoT.**

[104] KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

[105] Ernst & Young. *Smart Contracts Using Blockchain Technology: a better way to deliver construction projects.* IISD. 2022. *Infrastructure Tokenization: Does blockchain have a role in the financing of infrastructure?*

- **Application to infrastructure: IoT-based systems can help reduce traffic jams and pollution as well as water, light and energy usage, and are therefore used in many smart city concepts. The availability of data through IoT, and the speed at which the information is delivered, has improved efficiency, reduced costs, and increased transparency in the management of infrastructure. In Barcelona, for example, a citywide Wi-Fi and information network linked to sensors, software, and a data analytics platform has enabled the city to provide smart water technology, automated street lighting, remote-controlled irrigation for parks and fountains, "on-demand" waste pickups, digital bus routes and smart parking meters. These IoT-enabled urban services have dramatically reduced traffic jams and pollution, as well as water, light, and energy usage.[106]**

3D printing

- **Generic description:** 3D printing, also known as additive manufacturing or digital fabrication, makes it possible to produce real objects from computer-aided design (CAD) files by stacking material in layers until the physical object is formed. A designer draws the 3D object using a CAD tool or 3D scanner. The 3D file obtained is processed by specific software that allows the 3D printer to read the design and to print the material layer by layer until the final part is obtained.

- **Application to infrastructure:** Since it was developed in the 1980s, 3D printing has developed into a versatile technology that is used in more and more infrastructure sectors. With 3D printers now even able to build walls or process cement, 3D printing offers a broad range of applications for the construction of infrastructure assets, as well as for the on-site production of replacement parts for asset maintenance and repair. For example, when a component or structure needs to be duplicated in another location, use of 3D printing means that only the digital blueprint needs to be sent to the respective location, using 5G technology. The structure or component can then be assembled on site.[107] 3D printing therefore has the potential to reduce construction costs and delivery times significantly and will likely diminish wasted components. On the downside, the increased use of 3D technology will significantly reduce the market for transport and logistic services, and the need for supporting infrastructure (ports, etc.).[108]

Advanced materials

- **Generic description:** This category includes advances in the application of nanotechnology and emerging nanomaterials, which are produced by manipulating matter at the nanoscale (less than 100 nanometers). This level of manipulation allows for the development of materials that have greater reactivity, unusual electrical properties, and enormous strength.[109]

- **Application to infrastructure:** Nanomaterials have a wide range of applications for infrastructure projects. Nanomaterials could, for example, be used to engineer construction materials for more durable, economic, and resilient road surfaces with improved geotechnical properties that reduce costs and time for construction and maintenance.[110]

[106] Kranz, Maciej. 2018. "6 ways the Internet of Things is improving our lives." WEF, January 11, 2018. (Last visited September 13, 2022.)

[107] KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

[108] World Bank Group. 2020. *Infratech Value Drivers*.

[109] Texas A&M Transportation Institute. 2016. *Disruptive Technologies and Transportation*, Final Report.

[110] KPMG. 2020. "The Impact of Technological Disruption on Infrastructure." KPMG Insights, August 2020. (Last visited September 13, 2022.)

Appendix B: Disruptive Technology in the Energy Sector

The energy sector is currently undergoing a major transformation. Overall, the sector is shaped by a shift from fossil fuels to renewables; price drops in renewable energy technology and battery storage; and decentralization of centralized grids, while digitalization, AI, and related technologies make the energy sector "smarter."

(i) Shift from Fossil Fuels to Renewables

One major transition of the power sector is the shift from fossil fuels to renewable energy.[111] As of 2019, oil, natural gas, and coal collectively accounted for 84.3 percent of the share of total global energy consumed.[112] Global renewables consumption represents only 5 percent of the total share, but consumption continues to grow at a rate of 12 percent to 13 percent each year.[113]

Table A.1: Fuel Shares of Primary Energy and Contributions to Growth in 2019

Energy source	Consumtion (exajoules)	Annual change (exajoules)	Share of primary energy	Percentage point change in share from 2018
Oil	193.0	1.6	33.1%	-0.2%
Gas	141.5	2.8	24.2%	0.2%
Coal	157.9	-0.9	27.0%	-0.5%
Renewables*	29.0	3.2	5.0%	0.5%
Hydro	37.6	0.3	6.4%	-0.0%
Nuclear	24.9	0.8	4.3%	0.1%
Total	**583.9**	**7.7**		

*Renewable power (excluding hydro) plus biofuels

Source: BP. 2020. *Statistical Review of World Energy 2020*, 69th edition.

Renewable electricity capacity additions have been outpacing those of non-renewables since 2014. Over the past decade, renewables capacity increased by 130 percent, whereas non-renewables only grew by 24 percent.[114]

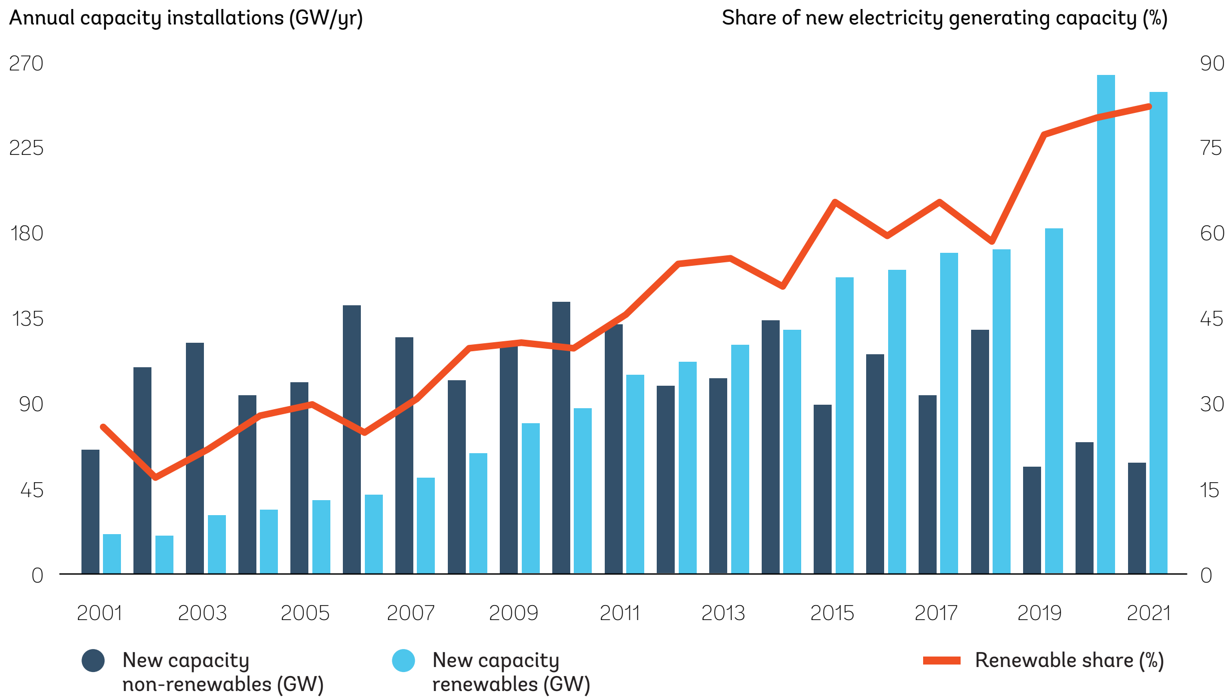
[111] Renewable energy sources are sustainable sources to generate power, the majority of which do not emit carbon. These sources include wind, solar, hydroelectric, hydrokinetic, biomass, and geothermal.

[112] BP. 2020. *Statistical Review of World Energy 2020*, 69th edition.

[113] BP. 2020. *Statistical Review of World Energy 2020*, 69th edition.

[114] IRENA. 2022. *World Energy Transitions Outlook 2022*.

Figure A.1: Share of New Electricity Capacity, 2001–2021



Source: IRENA. 2022. *World Energy Transitions Outlook 2022.*

Among renewable technologies, solar PV installations have seen the fastest growth, with a 21-fold increase in the 2010-21 period. By the end of 2021, the cumulative installed capacity of solar PV reached 843 gigawatts (GW) globally; 133 GW of capacity was commissioned in 2021 alone. Wind power also experienced significant growth, and wind installations increased more than four-fold from 2010 to 2021. In 2021, the cumulative installed capacity of onshore wind power reached about 769 GW across the globe. The offshore wind market remains small compared to onshore wind, with 56 GW of cumulative installed capacity by the end of 2021.[115]

Against this background, 2022 is set to be a record year in terms of the scale at which the switchover from fossil fuels to renewable sources will take place.[116] As the trend continues, it is possible to foresee fossil fuel infrastructure becoming more unattractive to investors and ultimately obsolete.

This development was to a large extent driven by international commitments and public policies. With increasing global awareness that fossil fuels are a main contributing factor to climate change, the worldwide ambition to decarbonize has grown significantly. This led to the adoption of the **Paris Agreement** on December 12, 2015,[117] under the United Nations Framework Convention on Climate Change (UNFCCC). The objective of the Paris Agreement is to respond to the threats of climate change by limiting the average global temperature increase, lowering greenhouse gas (GHG) emissions, and promoting climate-resilient development. It sets goals that require each country to reduce its emissions drastically. To achieve these goals, countries worldwide have adopted plans for actions, so-called Nationally Determined Contributions (NDCs), and based on their NDCs, introduced and implemented policies to reduce GHG emissions and to

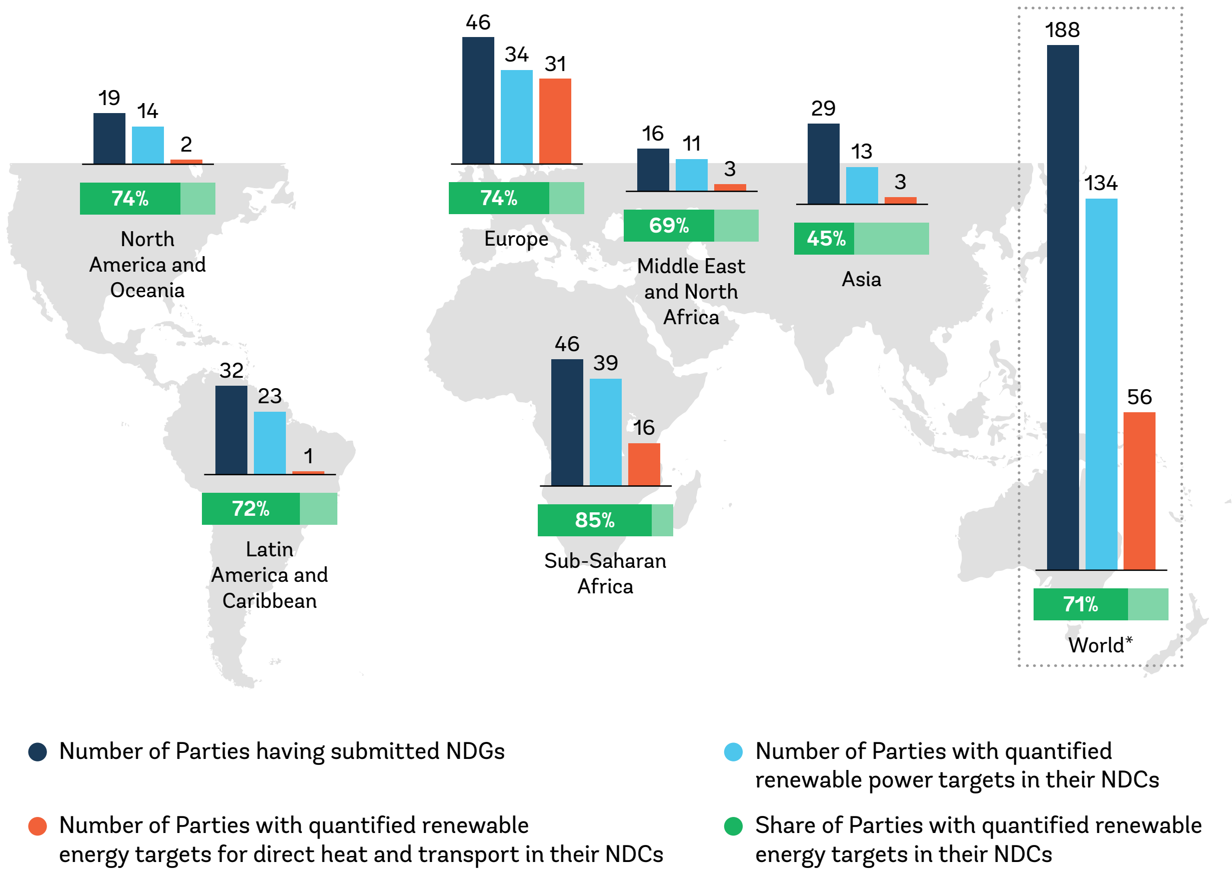
[115] IRENA. 2022. *World Energy Transitions Outlook 2022.*

[116] Marr, Bernard. 2022. "The Five Biggest New Energy Trends In 2022." *Forbes,* March 1, 2022.

[117] On December 12, 2015, 196 countries adopted the Paris Agreement, which has since then been ratified by 189 countries.

adapt to the effects of climate change. Although the NDCs vary among developed and developing countries, 71 percent of the parties included quantified targets to increase their share of renewable energy as a part of their NDCs. Of these parties, all included targets in the power sector, whereas a few also included targets in heating and transport.[118]

Figure A.2: Renewable Energy Components in Current NDCs



Note: Figures were last updated and verified on 9 December 2020.
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Source: IRENA. 2020. *Renewable Energy and Climate Pledges: Five Years after the Paris Agreement*.

[118] IRENA. 2020. *Renewable Energy and Climate Pledges: Five Years after the Paris Agreement*.

(ii) Renewable Energy Is Getting Cheaper and Cheaper

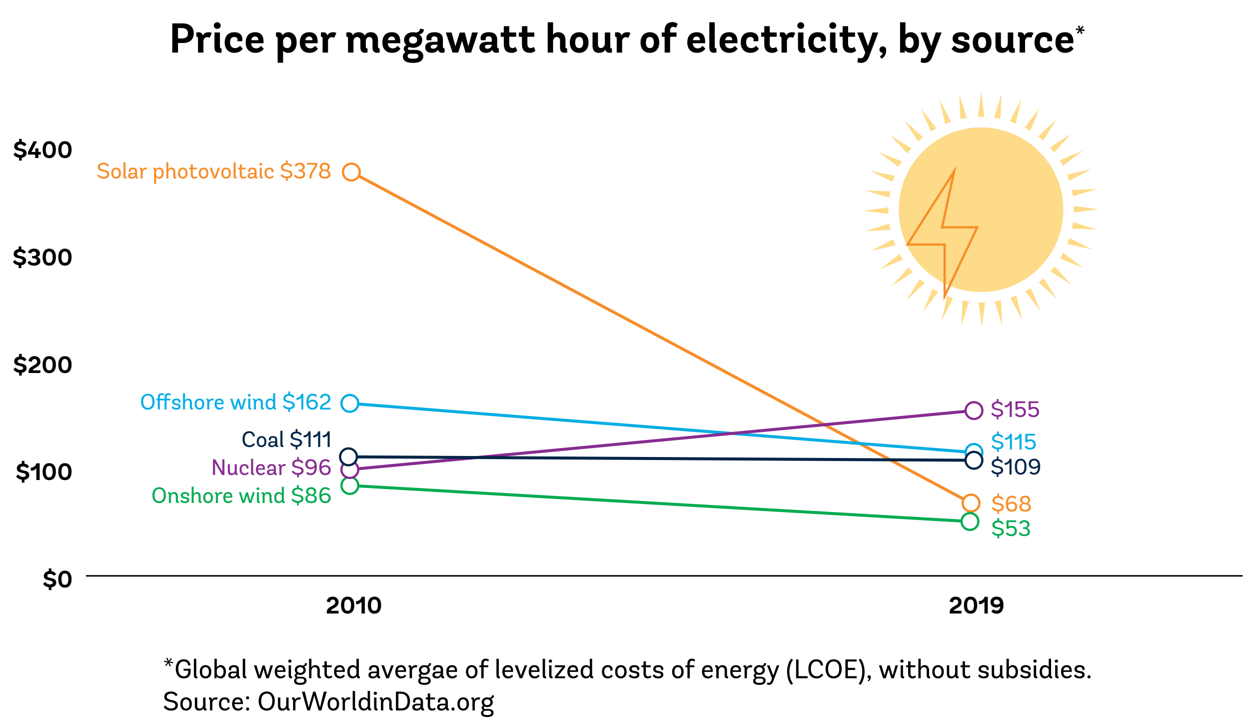
Another driver for the shift towards renewable energy—one that goes hand in hand with ambitious global climate change goals—is that the costs of renewables have been falling steadily during recent decades, making them increasingly the most cost-effective and sustainable energy source for transport, heating, and many industrial production processes. Renewables are now the cheapest power options in most regions.[119]

This development was initially spurred by a number of **support policies** to encourage renewable energy on the grid during a time when generation of renewable energy was not yet competitive. To reach global climate change targets, the deployment of renewable energy, in particular solar PV and wind generation, was bolstered by many national regulatory and pricing support mechanisms (e.g., feed-in tariffs).

Thanks to innovation and economies of scale, the **costs** of renewable energy generation technologies, e.g., solar PV panels, have **dropped steadily and drastically**. As improvements, for example to solar PV modules, enhanced efficiency, durability, and capacity, solar PV modules began to meet the demands of mainstream markets, thereby increasing production of the modules and decreasing prices exponentially.

In 2020, a total of 162 gigawatts (GW), or 62 percent of the total new renewable power generation capacity added globally, had electricity costs lower than the cheapest source of new fossil fuel-fired capacity. The global weighted-average levelized cost of electricity (LCOE) of newly commissioned utility-scale solar PV projects fell by 85 percent between 2010 and 2020, that of concentrated solar power (CSP) by 68 percent, and onshore wind by 56 percent and offshore wind by 48 percent. Renewables are now the default option for capacity additions in the power sector, where they dominate investments.

Figure A.3: The Falling Cost of Renewable Energy.



Source: Statistica. https://www.statista.com/chart/26085/price-per-megawatt-hour-of-electricity-by-source/.

[119] IRENA. 2022. *World Energy Transitions Outlook 2022*.

This price decline, together with **advances** and **price drops in battery storage technology**, in particular lithium-ion battery technology and green hydrogen (see "Stationary and mobile energy storage devices" in Appendix A) made efficient peak time provision of renewable energy possible, and further accelerated the adoption of renewable energy sources.

As the costs of renewables plummeted, the world started to **move from specific support mechanisms** that relied on high levels of direct government subsidies (e.g., feed-in tariffs) **to more competitive tool**s. Although feed-in policies remain a widely used policy mechanism for supporting renewable power, in 2020 the shift to competitive remuneration through tenders and auctions continued. In the first half of 2020, 13 countries awarded nearly 50 GW in new capacity, breaking a record for auctioned capacity. Although the total number of countries that held renewable power auctions decreased during the year (from 41 to at least 33), several new countries held auctions for the first time. Alongside significant and ongoing cost reductions in solar PV and wind power, the growth of auctions has created a highly competitive bidding environment that has placed strong downward pressure on price levels for renewable power projects. In 2020, developers around the world continued to submit bids for tenders at record-low prices for utility-scale solar PV and wind power.[120]

(iii) Decentralization

Another trend that can be witnessed is a switch from centralized power generation and large transmission nets to decentralized energy generation, where more power is generated closer to the point of consumption by smaller local power grids at competitive prices (e.g., solar farms).

With falling prices of renewable energy deployment as well as small-scale renewable power generation and storage technology, the energy sector has become less dependent on centralized utility scale power generation. Instead, distributed generation of electricity is steadily increasing, particularly within emerging and developing markets because it allows electricity to be produced onsite or near to where the electricity will be consumed, in areas that are not yet connected to a central grid. Advances in AI and other disruptive technologies have enabled distributed generation to become an even bigger component of global power generation, because the development and integration of numerous smaller networks requires complex AI algorithms.[121]

Centralized generation refers to the large-scale generation of electricity at centralized facilities. These facilities are usually located away from end-users and connected to a network of high-voltage transmission lines. The electricity generated centrally is distributed through the electric power grid to multiple end-users. Centralized generation facilities include fossil fuel-fired power plants, nuclear power plants, hydroelectric dams, wind farms, and more.

Distributed generation refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels, small wind turbines, or combined heat and power systems. Distributed generation can be interconnected with or independent from the centralized grid. It may serve a single structure, such as a home or business, and can also be part of a nanogrid or microgrid (smaller grids that are also tied into the larger electricity delivery system), such as at a major industrial facility. When connected to the electric utility's lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines.[122]

[120] Ren21. 2021. *Renewables 2021 - Global Status Report 2021*.

[121] Marr, Bernard. 2022. "The Five Biggest New Energy Trends In 2022." *Forbes*, March 1, 2022.

[122] The global average of losses during transmission and distribution is 8 to 9 percent of the electricity generated, although many developing countries see well over 20 percent of it lost (Electric power transmission and distribution losses (% of output). Data bank of The World Bank (last visited: September 13, 2022).

(iv) The Power Sector is Getting 'Smarter'

Together with the ability to generate power from renewables at very small scale and store it in batteries, digital technologies are re-shaping the energy sector. Around the globe, innovative digital solutions are increasingly implemented, ranging from smart meters and other IoT devices that can communicate with each other to smart grids, smart EV charging infrastructure, and smart city concepts. These innovative solutions will help improve power management, efficiency, and transparency, and will make it easier to manage the integration of renewables and the increasing number of EVs.

Smart grids are electricity networks that allow for two-way communication between the utilities, the consumers, and any intermediary third-party service providers. They use digital and other advanced technologies (e.g., smart meters, sensors, AI, IoT, and big data analytics) to collect, store and analyze data. Thereby they give utility operators a way to monitor and manage usage and network performance in real time, allowing them to meet the varying electricity demands of end users, to spot failures as they happen, and, under some circumstances, even to restore power by rerouting service around the failed transmission or generating equipment.[123] Smart grids coordinate the needs and capabilities of all generators, grid operators, end users, and electricity market stakeholders to operate all parts of the system as efficiently as possible with real-time data, minimizing costs and environmental impacts while maximizing system reliability, resilience, and stability.[124]

Smart EV charging infrastructure demand is rising. As the popularity of and need for EV rises, so does the demand for readily available public and private EV charging infrastructure. Such infrastructure is commonly seen as a necessary component of a smart grid. Electric vehicle supply equipment (EVSE) delivers electricity to EVs to recharge the vehicles' batteries. Currently, the majority of EVSEs are wired, and the EVs need to be plugged in for charging. With concerns related to battery range and plug-in options, wireless EV charging technology, known as wireless power transfer (WPT), has been developed and will likely be widely adopted in the near future.

Smart grid technology will be key for the deployment and flexibility of EV charging infrastructure. Because EVs are idle most of the time, they can be a tool for improving grid stability. Wide-scale use of EVs will dramatically increase global energy storage capacity, helping to harness renewable energy that would otherwise be lost. An EV's average useable battery capacity is about 40 kWh.[125] Smart grid technology will allow EVs with bidirectional charging capabilities to be distributed energy resources, supplying the grid during peak demand and offtaking excess electricity when supply is high, known as vehicle-to-grid (V2G) technology or vehicle-grid integration (VGI). Furthermore, EVs could also power home (vehicle-to-home, or V2H) and building (vehicle-to-building, or V2B) technology. Many EV manufacturers are now introducing bidirectional charging capabilities as a standard feature on new models.

[123] Manyika, James, Michael Chui, Jacques Bughin, Richard Dobbs, Peter Bisson, and Alex Marrs. 2013. *Disruptive technologies: Advances that will transform life, business, and the global economy*. McKinsey Global Institute.

[124] IEA (International Energy Agency). 2021. *Smart Grids*.

[125] Statista Research Department. 2021. "Estimated average battery capacity in electric vehicles worldwide from 2017 to 2025, by type of vehicle."

Appendix C: Disruptive Technology in the Transport Sector

Recent years have seen many technological developments that will have profound impacts on the transportation sector. It is anticipated that disruptive technologies (described in Appendix A, such as big data, machine learning, AI, IoT, 5G, and battery storage systems), the rise of the shared economy, and global pressure to lower carbon emissions will transform urban and long-distance passenger transport as well as transportation of goods and logistics. The transport systems of tomorrow will be more connected and data-driven, digitalized, shared and on-demand, cleaner, highly automated, and decentralized.[126]

Disruptive technology is transforming the transport sector in a variety of ways. To give a broad overview of the developments in the sector, five of the most prominent trends are summarized below.[127]

(i) Digital Connectivity and Cooperative Intelligent Transport Systems (C-ITS):

It is expected that digital connectivity and the utilization of cooperative intelligent transport systems are going to transform the transport sector. C-ITS are emerging technologies that allow for the generation, collection, and exchange of data among transportation system users (e.g., cars, trucks, ships, and locomotives) and other parts of the transportation infrastructure (e.g., roads, ports, and containers). The digital connectivity between these elements can make traffic and traffic management more efficient, safer, and cleaner. Vehicle-to-vehicle (V2V) connectivity refers to wireless data exchanges between vehicles about their locations, speed, or headings; vehicle-to-infrastructure (V2I) connectivity captures infrastructure-related data, such as traffic congestion and weather warnings, and transmits all relevant data to drivers; vehicle-to-everything (V2X) connectivity encompasses both V2V and V2I connectivity. V2X supports the transfer of information from a vehicle to all other moving parts of the traffic system that may affect the vehicle, as well as other parts of the transportation system, and allows, for example, for dynamic pricing of roadways and parking spaces. In the freight sector, connectivity enables fleet optimization and increased productivity, efficiency, safety and compliance, because it makes it possible to track the performance of transport assets in real time, including their locations.[128] One example is shipping containers used in freight and logistics that are integrated with IoT, sensors, GPS tracking, and solar panels. These smart containers can regulate internal conditions (e.g., temperature) to reduce cargo loss and provide real-time GPS tracking to optimize supply chain logistics.[129]

(ii) Sharing

In the transport sector, the shared use as well as shared ownership of cars, bicycles, scooters, and trucks continues to grow in popularity. The integration of disruptive technology (such as AI, big data, and IoT) into sharing systems facilitates smart booking and the development of new business models, and contributes to this trend. Sharing of vehicles has already led to a more efficient, easy, door-to-door and low-carbon method of transport. Among the various business models, the popularity of ride sharing has surged in recent years. Ride sharing is a car service in which the passenger travels in a privately owned vehicle against a fee based on an agreement between the owner of the car and the passenger, typically arranged with the help of online sites and smartphone applications. After a plunge in 2020 due to COVID-19, the global ride-sharing market is

[126] Muzira, Stephen, and Tatiana Peralta Quiros. 2018. "The future of transport is here. Are you ready?" Transport for Development (blog), World Bank, April 26, 2018.

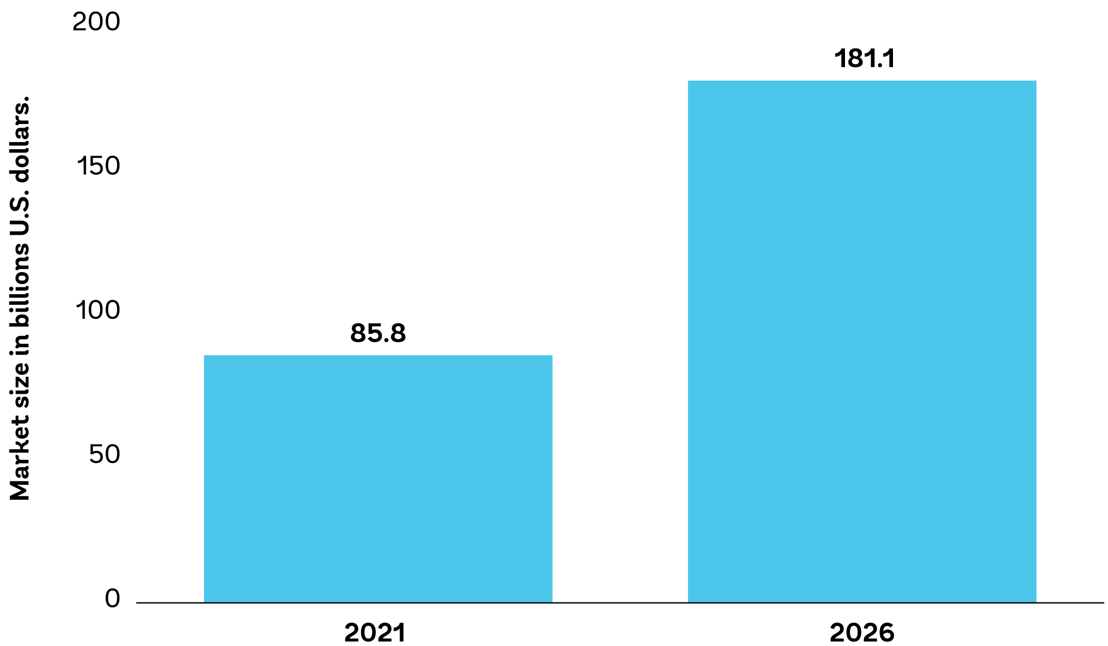
[127] Twinn, Ian. 2019. "Innovations in Transport." In *Reinventing Business through Disruptive Technology*. Washington, DC: International Finance Corporation.

[128] Twinn, Ian. 2019. "Innovations in Transport." In *Reinventing Business through Disruptive Technology*. Washington, DC: International Finance Corporation; Global Infrastructure Hub. 2020. *Vehicle to Infrastructure (V2I) Connectivity and Smart Motorways*.

[129] World Bank Group. 2020. *Infratech Value Drivers*.

now expected to grow by more than 115 percent from 2021 to 2026, according to the online portal Statistica. The market value is expected to amount to about US$185 billion in 2026. Other forms of sharing are bike-sharing programs, inner-city on-demand transportation through e-bicycles or e-scooters, and business-to-consumer car sharing, where vehicles are rented out by customers from a service provider.

Figure A.4: Ride Sharing Market Size Worldwide in 2021 and 2026



Source: Statistica. https://www.statista.com/statistics/1155981/ride-sharing-market-ize-worldwide/.

(iii) 'Greener' transport

Growing concern about climate change has created global pressure to reduce carbon emissions in the transport sector. To end the dependence on fossil fuels, alternative fuels like hydrogen are being explored. At the same time, vehicles that run by using electricity instead of fossil fuels are being developed and promoted. EVs are powered by electric motors and receive electricity by plugging into the grid. Hybrid electrical vehicles (HEVs) rely on a petroleum-based or an alternative fuel for power and are not plugged in to charge.[130] HEV batteries are charged by the internal combustion engine (ICE) or other propulsion source and during regenerative braking.[131] The use of electric vehicles is growing, including fully electric cars and hybrids, trucks, two- and three-wheelers, and bus rapid transit (BRT) lines. According to Bloomberg,[132] by June 2022, 20 million plug-in vehicles were expected to be on the road globally, compared with 1 million in 2016; that number is expected to reach 26 million by the end of 2022 (see "Autonomous Vehicles/Electric Vehicles" in Appendix A).

[130] United States Department of Energy. 2012. *Plug-In Electric Vehicle Handbook*.

[131] Regenerative braking refers to the generation of electricity from some of the energy that is normally lost when braking.

[132] McKerracher, Colin. 2022. "The World's Electric Vehicle Fleet Will Soon Surpass 20 Million." *Bloomberg*, April 8, 2022.

Although shipping and aviation were initially excluded from greenhouse-gas emission reduction targets, both are coming under increasing pressure to reduce their significant greenhouse gas emissions and other pollutants. As a consequence, the aviation industry has been experimenting with biofuels, and electric and hybrid electric-conventional aircrafts. Similarly, the maritime industry and vessel operators are adopting and developing technologies to help make vessels more efficient, including fuel cells and electric batteries with the capacity to power vessels over long distances.[133] Hyperloop is a proposed fast and carbon-neutral mode of ground transport for passenger and freight transportation between cities.[134]

(iv) Automation

Automation that is enabled through disruptive technology is applied in various ways in the transportation sector, ranging from online booking systems to drones and autonomous vehicles (including passenger cars, taxis, trucks, buses, and trains), and there is also automation at roads, terminals, and logistic centers. Self-flying taxis that are currently being trialed in Dubai also belong in this category. The level of automation for vehicles has been subject to categorization ranging from level 0 (no automation) to level 5 (full automation).[135] By 2040, autonomous vehicles are expected to comprise about 25 percent of the global market.[136] (See also "Autonomous Vehicles" and "Drones" in Appendix A.)

(v) Decentralization

As in the power sector, disruptive technology will likely also result in more decentralization in the transport sector. The availability of ride-sharing systems and autonomous vehicles may, for example, lead to a shift from public transportation systems to individual transport.

133 Twinn, Ian. 2019. "Innovations in Transport." In *Reinventing Business through Disruptive Technology*. Washington, DC: International Finance Corporation.

134 Global Infrastructure Hub. 2020. "Hyperloop for High-Speed Passenger Transport." (Last accessed September 13, 2022.)

135 Rodrigue, Jean-Paul. 2020. "Forms of Transport Automation." *The Geography of Transport Systems*, Fifth Edition (section of book reproduced on personal website, from Chapter 10: "Challenges for Transport Geography"). New York: Routledge.

136 *MIT Technology Review Insights* (blog). 2017. "Autonomous Vehicles: Are You Ready for the New Ride?" November 9, 2017. (Last visited September 13, 2022.)

The World Bank Group provides assistance to governments in developing countries to improve access to infrastructure and basic services through public-private partnerships (PPPs). When designed well and implemented in a balanced regulatory environment, PPPs can bring great efficiency and sustainability to the provision of such public services as water, sanitation, energy, transport, telecommunications, healthcare, and education.

The World Bank Group's unique value proposition rests with its capacity to provide support along the entire PPP cycle—upstream policy and regulatory guidance, transaction structuring advice, as well as financing and guarantees to facilitate implementation.

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