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Challenges and Potential Support Mechanisms for Renewable Energy Deployment in Developing Countries

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TESI DOCTORAL

Challenges and Potential Support Mechanisms for Renewable Energy Deployment in Developing Countries

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Memòria presentada per optar al grau de Doctor per la Universitat de Lleida
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Challenges and Potential Support Mechanisms for Renewable Energy Deployment in Developing Countries

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CERTIFICA:

Que la memòria “Challenges and Potential Support Mechanisms for Renewable Energy Deployment in Developing Countries” presentada per Hugo Lucas Porta per optar al grau de Doctor s’ha realitzat sota la seva supervisió.

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Summary

Developing countries face the dual challenge of having to contribute their share to climate change mitigation while simultaneously trying to urgently promote sustainable development. Given that the latter is correlating positively with energy demand, the former can only be achieved when developing countries manage to decarbonise their power sectors.

The thesis seeks to explore the unique challenges to renewable energy deployment is conducted for the case of Pacific Small Island Development States, highlighting the need for targeted policy intervention and the need to unlock private finance and investment. The analysis has also shown that energy transitions in developing countries may be severely slowed down due to widespread human capacity deficits. Human capacity deficits and the lack of adequate education and training offers were evaluated through an analysis of IRENA's IRELP database. Results are indicative of a significant mismatch between quantity and quality of education and skills which, the emerging renewable energy sectors seek and, what education providers are capable to supply, representing a critical structural barrier to efficient renewable energy deployment, especially in developing countries.

Renewable energy procurement auctions in developing countries are subsequently evaluated with respect to their capability to significantly incentive private investments into renewable energy sectors in Sub-Saharan Africa, while at the same time minimizing support costs by competitively driving down the price of electricity generated from renewables. These features, as well as the adaptability of auctions to cater also to secondary policy objectives and priorities, render them highly attractive to policy makers in developing countries. Further, the applicability and success of auction mechanisms in the context of rural electrification service procurement were analysed, based on experience from Peru, confirming auctions adaptability and flexibility to specific contexts.

Auctions are, however, not a one-fit-all solution, and while extensive structural barriers to renewable energy deployment, such as human capacity deficits, can theoretically be addressed via the diligent composition of adequate design elements, this will always result in efficiency trade-offs. This thesis suggests that auctions are ideally an integrated component of a wider aligned and reinforcing policy mix.

Resum

Els països en desenvolupament enfronten el doble desafiament d'haver de contribuir amb la seva part a la mitigació del canvi climàtic i, al mateix temps, tractar de promoure amb urgència el desenvolupament sostenible. Atès que aquest últim es correlaciona positivament amb la demanda d'energia, el primer només es pot aconseguir quan els països en desenvolupament aconsegueixen descarbonitzar els seus sectors d'energia.

La tesi porta a terme un anàlisi dels desafiaments únics per al desplegament d'energia renovable per al cas dels Petits Estats Insulars en Desenvolupament de Pacífic, destacant la necessitat de polítiques específiques i desbloquejar finances i inversions privades . L'anàlisi també ha demostrat que les transicions energètiques en els països en desenvolupament poden reduir-se, dràsticament, a causa dels dèficits de capacitat humana. Els dèficits de capacitat humana i la manca d'ofertes adequades d'educació i capacitació es van avaluar mitjançant una anàlisi de la base de dades IRELP de IRENA. Els resultats indiquen un desajust significatiu entre la quantitat i la qualitat de l'educació i les habilitats que busquen els sectors d'energia renovable, el que representa una barrera estructural crítica per al desplegament eficient d'energia renovable, especialment, en els països en desenvolupament.

S'avaluen posteriorment les subhastes d'energia renovable pel que fa a la seva capacitat per incentivar, les inversions privades en sectors d'energia renovable a l'Àfrica subsahariana, al mateix temps que es minimitzen el preu de l'electricitat generada a partir d'energies renovables. Aquestes característiques, així com l'adaptabilitat de les subhastes per atendre també a objectius polítiques secundàries, les fan molt atractives per als encarregats de formular polítiques en els països en desenvolupament. A més, es va analitzar l'aplicabilitat i l'èxit dels subhastes en el context de la contractació de serveis d'electrificació rural, amb base en l'experiència del Perú, confirmant l'adaptabilitat i flexibilitat de les subhastes a contextos específics.

No obstant això, les subhastes no són suficient, i si bé les barreres estructurals extenses per al desplegament d'energia renovable, com els dèficits de capacitat humana, poden abordar teòricament a través de disseny adequats, això sempre resultarà en compensacions d'eficiència. Aquesta tesi suggereix que les subhastes són, idealment, un component integrat d'una combinació de polítiques més àmplia i alineada.

Resumen

Los países en desarrollo enfrentan el doble desafío de tener que contribuir con su parte a la mitigación del cambio climático y, al mismo tiempo, tratar de promover con urgencia el desarrollo sostenible. Dado que este último se correlaciona positivamente con la demanda de energía, el primero solo se puede lograr cuando los países en desarrollo logran descarbonizar sus sectores de energía.

La tesis lleva a cabo un análisis de los desafíos únicos para el despliegue de energía renovable para el caso de los Pequeños Estados Insulares en Desarrollo del Pacífico, destacando la necesidad políticas específicas y desbloquear finanzas e inversiones privadas. El análisis también ha demostrado que las transiciones energéticas en los países en desarrollo pueden reducirse drásticamente debido a la falta de recursos humanos. Los déficits de recursos humanos y la falta de ofertas adecuadas de educación y formación se evaluaron mediante el análisis de la base de datos IRELP de IRENA. Los resultados indican un desajuste significativo entre la cantidad y la calidad de la formación ofertada y las habilidades que busca el sector de las energías renovables, lo que representa una barrera estructural crítica para el despliegue eficiente de energía renovable, especialmente en los países en desarrollo.

Se evalúan, posteriormente, las subastas de energía renovable con respecto a su capacidad para incentivar inversiones privadas en el África subsahariana, al mismo tiempo que se minimiza el coste de la generación renovable. Esta característica, así como su adaptabilidad para promover al mismo tiempo objetivos políticos secundarios, las hacen muy atractivas para los países en desarrollo. Además, se analizó la aplicabilidad y el éxito de las subastas en el contexto de la contratación de servicios de electrificación rural, con base en la experiencia del Perú, confirmando la adaptabilidad y flexibilidad de las subastas a contextos específicos.

Sin embargo, las subastas no son suficiente, y si bien las barreras estructurales extensas para el despliegue de energía renovable, como los déficits de recursos humanos, pueden abordarse teóricamente a través de su diseño, esto siempre reducirá su eficiencia. Esta tesis sugiere que las subastas son, idealmente, un componente integrado de una combinación de políticas más amplia y alineada.

Nomenclature

BNEF	Bloomberg New Energy and Finance
CCGT	Combined Cycle Gas Turbine
CfD	Contract for Differences
CSP	Concentrated Solar Power
DRE	Decentralized Renewable Energy
EU	European Union
EUR	Euro
FIT	Feed-in tariffs
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HDI	Human Development Index
IEA	International Energy Agency
IPCC	Intergovernmental Panel for Climate Change
IPP	Independent Power Producers
IRELP	IRENA Renewable Energy Learning Partnership
IRENA	International Renewable Energy Agency
MSc	Magister Scientiae
NGO	Non-governmental Organizations
NREL	National Renewable Energy Laboratory
PNG	Papua New Guinea
PPA	Power Purchase Agreements
PV	Photovoltaic
RE	Renewable Energy

REC	Renewable Energy Certificate
REIPPP	Renewable Energy Independent Power Procurement Programme
SIDS	Small Island Developing States
STEM	Science, Technology, Engineering and Math
UAE	United Arab Emirates
UN	United Nations
UNESCO	United Nations Education, Science, and Cultural Organisation
USD	United States Dollar
UK	United Kingdom
VET	Vocational Education and Training
WEO	World Energy Outlook
WWF	World Wide Fund for Nature

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1.1 Introduction

1.1.1 Global Progress on Renewable Energy Deployment

Renewable Energy Capacity Today

The global total renewable energy capacity in 2019 was estimated at about 2.5 TW, more than 1200 GW of which were non-hydro (IRENA, 2020). This implies that more than 1/3 of global power capacity was accounted for by renewables, the result of momentum stemming from the more than 160 countries actively pursuing deployment and expansion targets (REN21, 2019). With respect to total installed renewable energy, significant geographical differences however remain. Most capacity is concentrated in Asia (1.1 TW), ranking in front of Europe (0.5 TW) and North America (0.4 TW) (IRENA, 2020), see Figure 1. These regional differences are also reflected when portraying solar and wind energy in isolation as shown in Figure 2 and Figure 3, with Asia maintaining the lead as the region with the highest capacity for both technology types.

Progress on renewable energy deployment in emerging and developing countries is quite significant. Developing and emerging countries' renewable capacity expanded by more than 100 GW in 2018, of which solar PV is contributing more than 50% (BloombergNEF, 2019). Fossil fuel-based capacity expansion in developing and emerging countries comprise ca. 30% of total added capacity in 2018, although accounting for more than half of additional generation (BloombergNEF, 2019). Renewable energy capacity additions in emerging countries are however driven mainly by developments in China and India, while for example the African energy transition is yet to pick up pace.

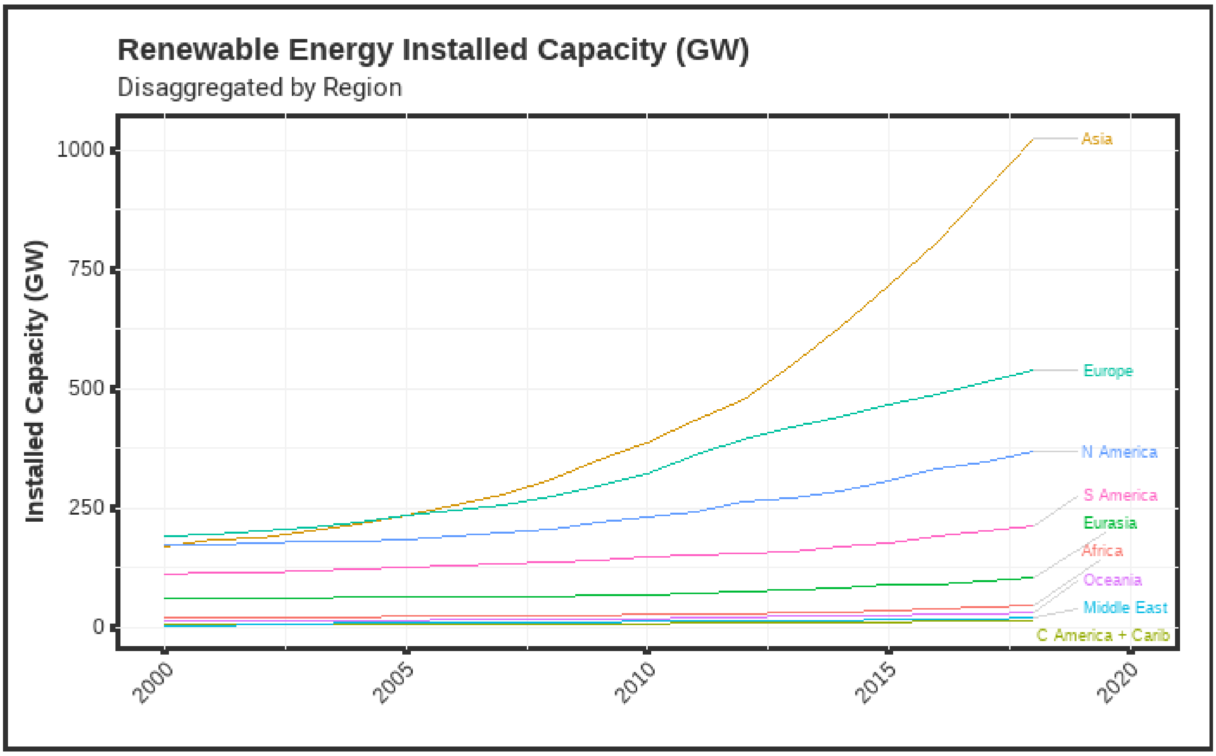


Figure 1:Renewable Energy Installed Capacity, based on IRENA (2020)

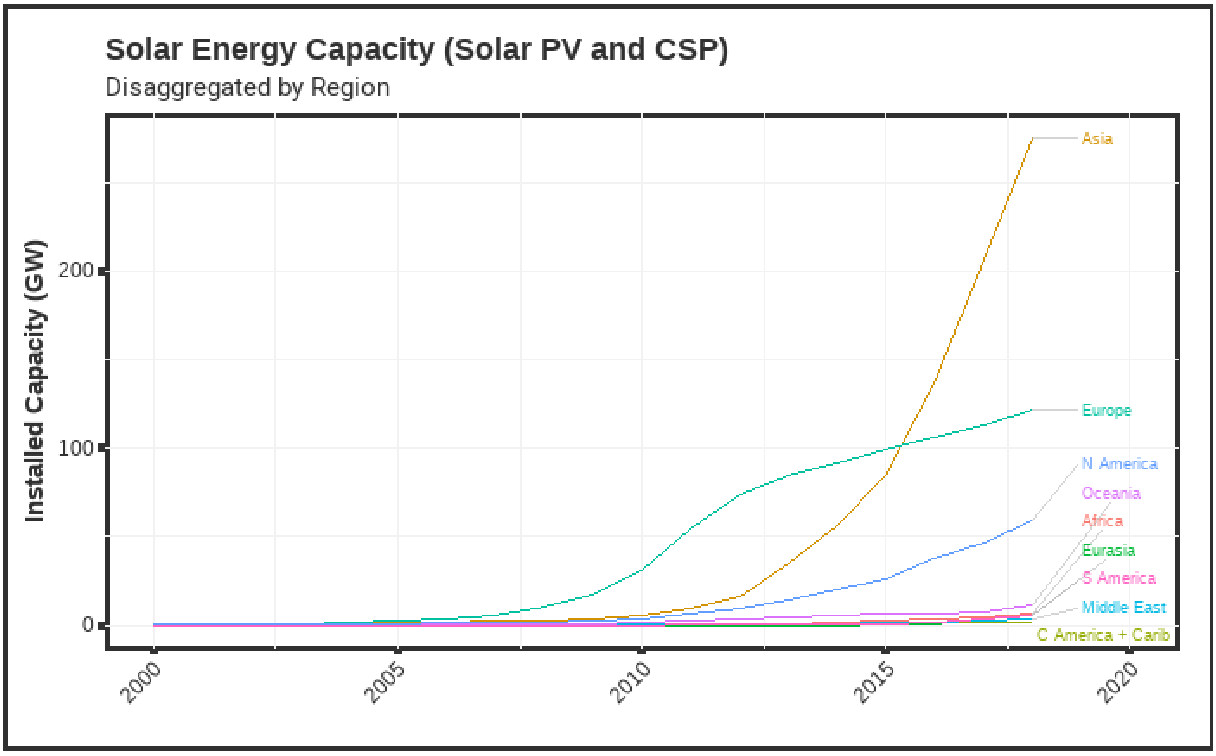


Figure 2: Solar Energy Capacity, based on IRENA (2020)

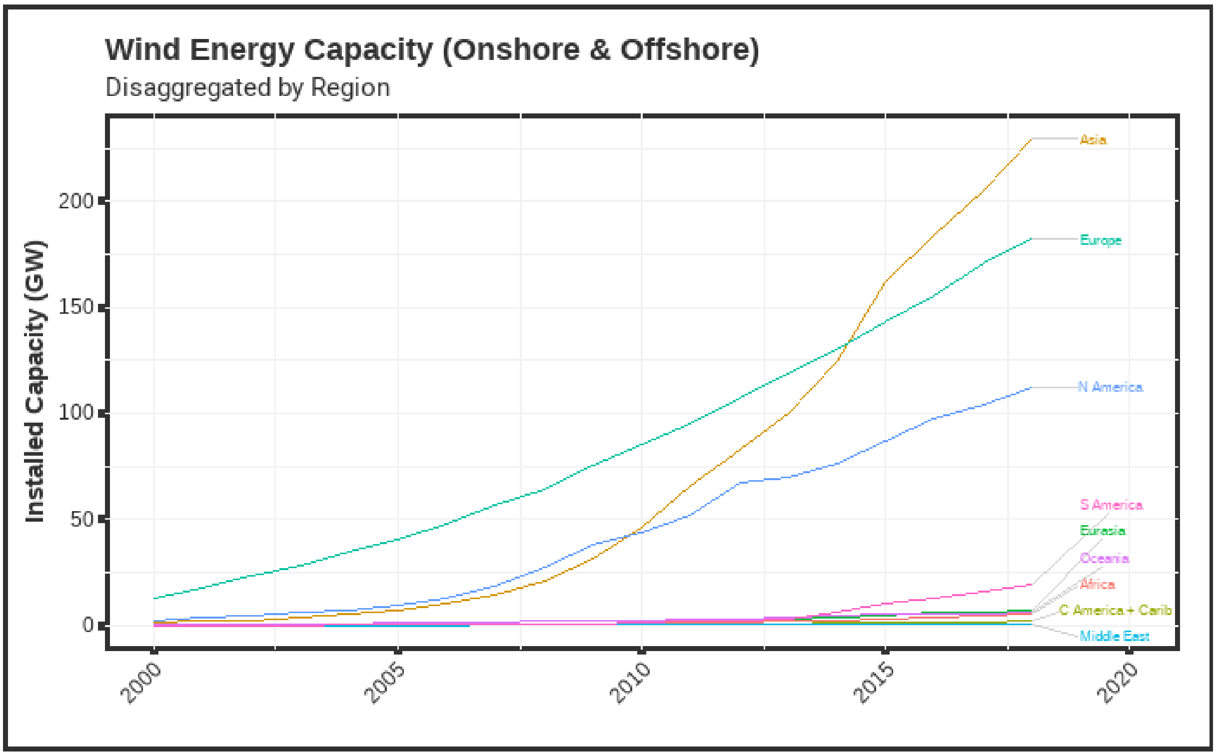


Figure 3: Wind Energy Capacity, based on IRENA (2020)

Energy Transition: Stable Progress

The expansion of renewable energy has picked up stable momentum, but the current pace of expansion is unlikely to be sufficient. Global primary energy consumption is growing rapidly, at a rate of 2.9% in 2018, significantly above its long-term average (BP, 2019). This upsurge in energy demand is driven by global economic performance, as well as climate change induced increases in heating and cooling needs. In 2018, renewable energy contributed a mere 5% to global primary energy generation (IEA, 2020a), which explains why the increase in energy demand, to a large extent, was met primarily by an expansion of fossil fuel based generation, most significantly through gas fuelled generation (BP, 2019).

Although its contribution to primary energy generation remains marginal, in 2018, renewable energy grew by almost 15%, rendering it the most rapidly growing energy source in the power sector (BP, 2019). By the end of 2018, renewable energy had provided approximately a quarter of global electricity generation (REN21, 2019). The year 2018 brought capacity additions of more than 180 GW of renewable energy, rendering renewables to account for more than 1/3 of global installed power generating capacity (REN21, 2019). However, the growth in electricity demand (about 4%) in 2018 (see Figure 4 for a regional comparison) was met only in part by the expansion in renewable energy, with also coal-fired electricity generation having exhibited expansion trends of scale and magnitude, thereby also threatening ongoing coal phase-out efforts (IEA, 2019b). Recent evidence suggests, however, that 2019 has been the first year on record, where the expansion of renewable electricity generation outgrew increases in global power demand (International Renewable Energy Agency, 2020).

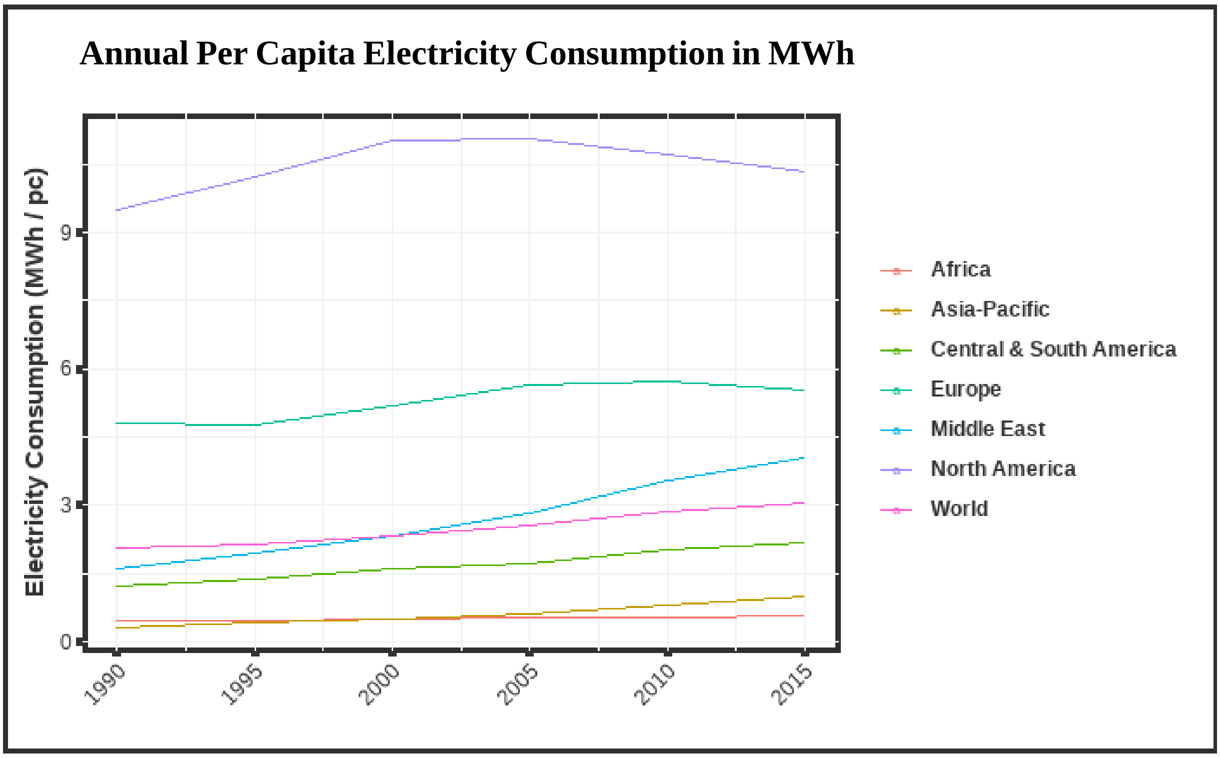


Figure 4: Per Capita Electricity Consumption, based on IEA (2020b)

In the power sector, decarbonisation is feasible and a Paris Agreement (PA) compliant transition is possible, at least in theory (Welsch, 2017). IRENA (2019a) estimates that a PA compliant growth trajectory in the power sector would demand an increase in renewable energy from 25% in 2018 to 85% by 2050. Naturally, this is dependent on the significant and scaled deployment of renewable energy technology in a way that represents a real transition away from fossil fuelled generation, ensuring that renewable energy expansion is not just happening in parallel to abiding or even expanding hydrocarbon infrastructure (York and Bell, 2019). Clearly, this is further dependent on a paradigm shift in the power sector's regulation and public policy, reflecting the role of electricity as the most important energy carrier, also beyond the boundaries of the power sector.

A Discrepancy Remains

A notable discrepancy between what it expected and required from a global energy transition, and what is actually implemented and achieved, has emerged (IEA, 2019e). On a global level, and driven by the rising energy demand, global energy-related CO2 emissions have grown by 1.7% in 2018, while in fact current annual emission levels are required to be halved by 2040 (IEA, 2019a). Globally, the IEA estimates that established and pledged policies and targets are inadequate to render countries' development trajectories PA compliant, if no significant policy-related paradigm shift can be leveraged (IEA, 2019a).

The same argument applies when portraying the power sector in isolation: GHG emissions have been growing at rates of around 2.5% in 2017 and 2018, while a PA compliant growth pathway would demand an annual decline in emissions of on average 4.1% until 2030 (IEA, 2019d).

Stronger penetration of renewable energy may prevent falling short of the emission reduction targets, but a huge funding need continues to represent a fundamental challenge: Global investments into renewables have somewhat stagnated in monetary terms since 2010, see Figure 5. This can partly be explained by falling technology costs, but there is consensus that current investment appetite will not suffice. IEA and IRENA (2017) estimate required additional investments into the power sector to amount to 3.5 trillion USD until 2050, on average per year, in order to follow a sustainable and PA compliant development trajectory. 15 trillion USD of investments are estimated to be required until 2050 for renewable energy capacity alone (IRENA, 2019c). Finance needs are especially paramount in developing countries, but access to funding is challenging in most emerging and developing countries, which is reflected by the low shares of investments that these countries are attracting, especially in Africa (Eicke, Weko and Goldthau, 2019).

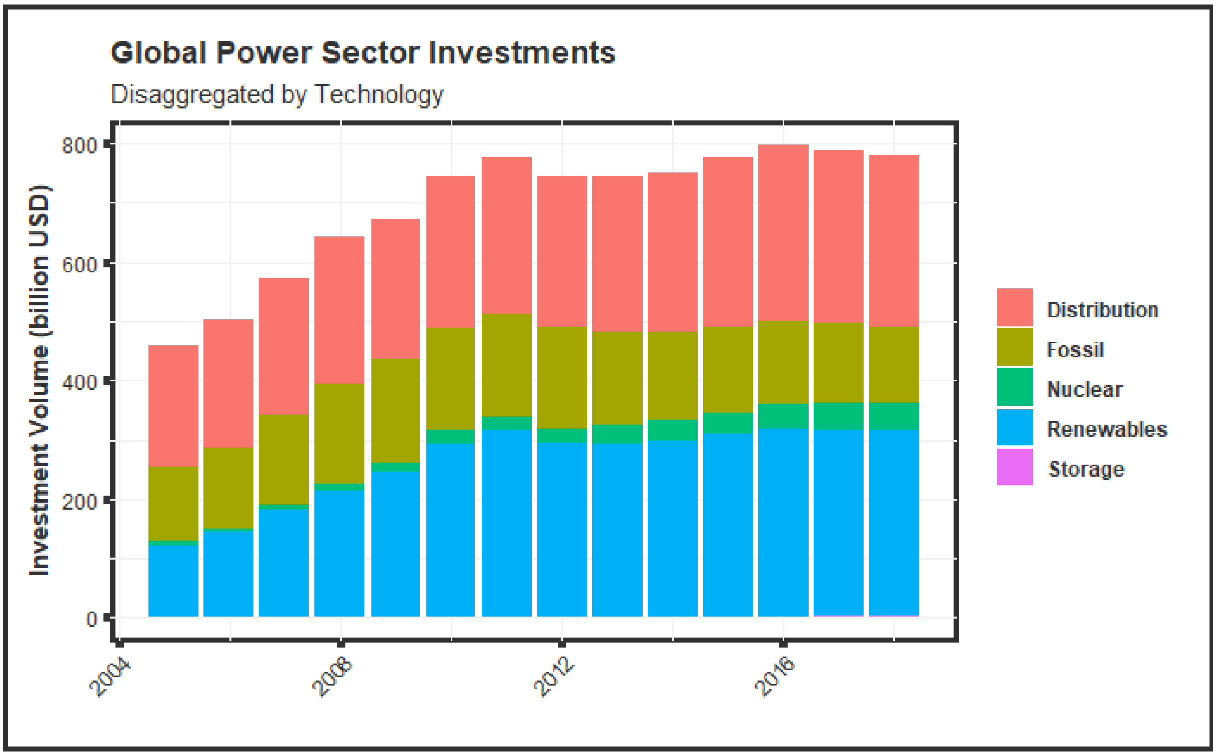


Figure 5: Power Sector Investments, based on IEA (2020b)

1.1.2 Progress on Renewable Energy Deployment in the Global South

Energy Transitions versus Economic Growth: A Trade-Off?

The world must undergo a global energy transition that is inclusive and integrative of also developing countries' ambitions to transition towards low carbon energy systems. For developing and emerging countries, however, the anticipated transition represents a significant structural disruption likely to have an even stronger impact on economy and society than it is the case for developed countries. Perspectives, priorities, and the general understanding of transition pathways, may differ substantially, depending on the country and development context. While energy transitions in the developed world are characterized by efforts to deploy renewable energy capacity in an attempt to substitute away from fossil fuels, in many developing countries the deployment of renewables may enable a "leapfrogging" of the fossil fuel era and hence the avoidance of fossil fuel dependence and technological lock-in. The idea of avoiding fossil fuel entry is compelling and attractive, however, the notion of the developing world leaping into a decarbonised energy future is contested, and may conceal too much of the challenges that remain (Murphy, 2001).

The large-scale deployment of fossil fuels, and especially coal, marks the onset of the industrial revolution in Europe. New technologies and the utilization of fossil-based energy unlocked significant productivity increases, social welfare gains and rapid economic growth, driven by mechanisation, efficiency improvements in manufacturing, cost reductions and sustained innovation (Pearson and Foxon, 2012). Energy was found to be an important production factor for modern economic growth and in the building-up of physical capital stock during these times (Jakob *et al.*, 2014), and as such its deficiency represents a critical constraint to growth (Stern and Kander, 2012). With the global community under the leadership of developed countries urgently pushing for a global transition away from those resources that have fuelled their wealth, developing and emerging countries may increasingly find themselves facing seemingly opposing priorities, i.e., that of economic growth and GHG emission reduction. The argument is not without support, as there is empirical evidence that economic development remains to be closely correlating with fossil fuel based primary energy consumption in emerging countries (Jakob, Haller and Marschinski, 2012) and for countries facing the onset of their industrial revolution (Jakob *et al.*, 2014).

Consensus is however building up that this alleged trade-off is not definite, and that a transitioning towards renewable energy may comprise a decoupling of fossil fuels from economic growth even in contexts where energy demand is growing (York and McGee, 2017). This is important, given that an increase in energy demand of 50% is estimated until 2050 (against 2018 levels), mostly stemming from dynamic growth in non-OECD countries (EIA, 2019). Efforts are directed at finding ways for detaching economic growth in developing countries from fossil fuel-based energy generation, and recent evidence indeed signals that renewable energy deployment in developing countries is a determinant of long-term economic growth (Fotourehchi, 2017). Further support for the economic rational of renewable energy deployment in developing countries is provided by Ito (2017) and Apergis and Danuletiu (2014) in cross-country panels of developing countries.

Energy Transitions in Developing Countries: Ensuring Universal Access Provision

An important conceptual difference of energy transitions in developing countries to those in developed countries is the difference in their energy transition’s point of departure. For developing countries, their energy transition comprises the establishment of reliable, modern and clean energy services throughout the country, in both rural and urban settings. This, however, does not necessarily represent a transition away from fossil fuel-based generation, but one that is initially required to shift consumption patterns away from traditional sources of energy (e.g. biomass) and as a result ideally also renders fossil fuel-based generation obsolete.

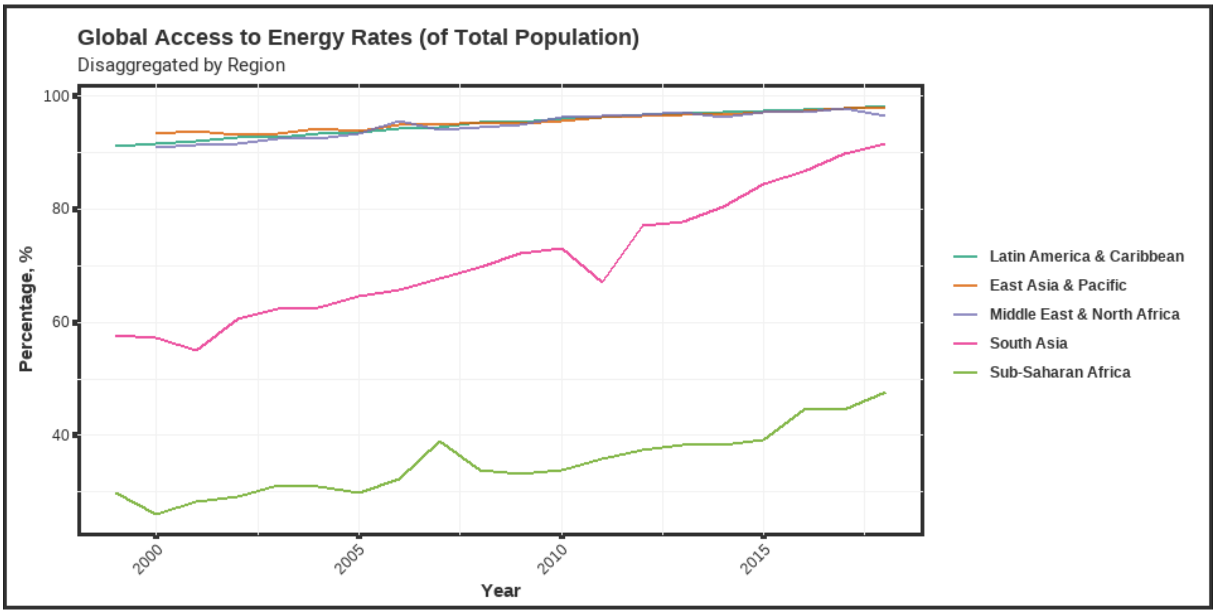


Figure 6: Electricity Access Rates, based on SE4ALL, (2019)

Ensuring universal access to reliable, modern, affordable and clean energy remains a significant challenge for more than 50 countries worldwide (GIZ, the greenwerk. and RLI, 2020). Energy access rates remain worryingly low in some regions of the world, see Figure 6. In 2018, the number of people without access to electricity stood at 860 million (IEA, 2019c), with the actual number of people only having unreliable access to electricity, for example due to insufficient distribution service levels (outages), likely to be much larger. Important progress on the electrification of rural areas, especially in Asia, has pushed the number of people lacking access to electricity below 1 billion in 2017 (REN21, 2019), but progress is unevenly distributed and population growth has led to some African countries' electrification rates to actually decline over recent years. For these countries, the prospect of a transition towards clean, modern and reliable energy for all is most imperative and represents an energy security concern, given the socioeconomic relevance of access to energy for human and economic development, also and especially in rural areas (Sokona, Mulugetta and Gujba, 2012).

Progress on electrification is enabled through the extension of centralized generation and distribution assets, or through the deployment of decentralized energy generation systems (mini-grids or stand-alone systems). The former approach is slow and not economically viable for dispersed populations (Bhattacharyya and Palit, 2016), and the expansion’s pace depends on the capacities of traditionally underfunded and indebted national utilities, proving unviable for ensuring fast electricity service propagation. Decentralized systems, primarily based on mini-grids or stand-alone solar PV and wind (plus storage or back-up), are more flexible, cost-effective and have become the most rational solution in many developing countries (Urmee and Md, 2016), in Sub-Saharan Africa (Amuzu-Sefordzi *et al.*, 2018), in Asia and the Pacific (Sharma, 2018), as well as specifically in Nigeria (Oyedepo *et al.*, 2018), in South Africa (Baruah and Enweremadu, 2019) and in India (Vallecha and Bhola, 2019), to name just a few examples. Decentralized systems have become affordable, reliable, and powerful, capable of powering refrigeration units, TV sets and even productive use appliances (Hirmer and Guthrie, 2017). Remarkable and ongoing technology cost reductions allow for decentralized systems to be competitive with alternative (diesel) and traditional sources of energy (e.g., biomass), and innovative business models operating on micro-loan or pay-as-you-go schemes have rendered the technology accessible to the rural and urban poor (Uppari, Popescu and Netessine, 2018).

In many ways, decentralized renewables comprise a transition pathway for developing countries that promotes energy security, sustainability and that critically facilitates human development (e.g., education, access to better healthcare, equality, poverty reduction, food security, etc.) and economic development (e.g., access to finance, infrastructure development, industrialisation) (Zhang *et al.*, 2019), targeting those most in need (Sharma (2018); Shoaib and Ariaratnam (2016)).

As summary for this introduction, a notable discrepancy between what it expected and required from a global energy transition, to reach the Paris Agreement climate goals, and what is actually implemented and achieved, has emerged. Furthermore, while in recent years, considerable new renewable energy capacity is being deployed, this are significant geographical differences, most of this capacity is added in China, India, North America and Europe.

While energy transitions in the developed world are characterized by efforts to deploy renewable energy capacity in an attempt to substitute away from fossil fuels, in many developing countries the deployment of renewables may enable a “leapfrogging” of the fossil fuel era and hence the avoidance of fossil fuel dependence and technological lock-in.

Consensus is however, building up that transitioning towards renewable energy may comprise a decoupling of fossil fuels from economic growth even in contexts where energy demand is growing. In addition to powering a sustainable economic growth, ensuring universal access to reliable, modern, affordable and clean energy remains a significant challenge for more than 50 countries worldwide. Decentralized renewables comprise a transition pathway for developing countries that promotes universal access.

1.2 Understanding the Drivers and Barriers to Renewable Energy Deployment - Globally and in Developing Countries

Determinants of Renewable Energy Deployment are Complex

To match existing and growing energy demand and to not rely on fossil fuels, countries need to scale up renewable energy deployment. According to a metanalysis of the factors influencing heterogeneous renewable energy deployment realities of countries conducted by Can Şener, Sharp and Anctil (2018), it is especially economic and regulatory factors that are affecting the deployment of renewables, both positively or negatively. The authors further highlight the importance of social dimensions, such as public confidence or interest, environmental dimensions, such as air pollution and CO2 emissions, as well as technical dimensions, such as renewable energy resource potential and land area. For most factors, Can Şener, Sharp and Anctil (2018) cannot define effect pathways unambiguously (i.e., factors can be drivers and / or barriers); a finding which finds general support also in an analysis of empirical determinants of renewable energy deployment conducted by Bourcet (2020). Renewable energy deployment is not determined by specific factors in isolation, but instead it is the overall context or framework which is required to be supportive. As such, policymakers must define strategies and policies that are capable of addressing existing barriers comprehensively.

1.2.1 Political and Regulatory Factors

Security of Supply: A Primary Motivator

A fundamental political factor affecting the pace and scale of the deployment of renewable energy capacity is the protection of the security of energy supply, in light of expected energy demand growth, the globally growing concerns regarding the need to mitigate global warming and local pollution, the need to ensure independence from depletable and price-volatile fuels, but also taking into consideration the intermittency aspect of most renewable energy sources (Johansson, 2013). Energy systems reliant on reserves of fossil resources are unlikely to adequately provide the energy generation capacity to match projected global growth of energy demand, due to affordability / price volatility issues, availability concerns (fossil fuels are after all finite), as well as with respect to fossil fuel-based energy systems' resilience to climate change threats (for example in a natural disaster context) (Valentine, 2011). These factors represent compelling arguments for the transition towards energy systems based on non-depletable and renewable resources, also and especially in developing and emerging countries, where energy demand is likely to grow most rapidly (Asif and Muneer, 2007).

On the other hand, energy systems with high shares of intermittent renewable energy generation can also bear risks to energy security, where energy system design inadequately accounts for renewable-based generation's inherent variability and unpredictability (Johansson (2013); Amusat, Shearing and Fraga (2017)). Whether 100% renewable energy based energy systems are technically or economically viable has been and still is contested (see for example Heard *et al.*(2017)), but generally the notion persists that technology advances (and cost reductions) on the storage front, coupled with a comprehensive reconceptualization of the logic of energy systems (e.g., the role of consumers and producers and distributors, and sector coupling more generally) pave the way for at least net-zero or even net-negative energy systems (Khalilpour, 2018) (Miller, 2020), while upholding the security of supply also when the sun goes down and the wind stops.

Ensuring security of energy supply is also and especially of tremendous importance for developing countries. Ensuring reliable and uninterrupted energy supply remains central to driving industrial development, economic growth and human development, and security of adequate generation capacity is as such essential especially where energy demand growth is as dynamic as it is in developing countries (Kuik, Lima and Gupta, 2011). Even more so, establishing energy supply and the security thereof is a number one priority for developing countries facing electrification gaps, i.e., where universal electrification is not achieved. The lack of access to clean and reliable forms of energy represents a huge development barrier in more than 50 countries around the world and especially on the African continent (GIZ, the greenwerk. and RLI, 2020). Insufficient access to modern forms of energy directly impedes progress on multiple Sustainable Development Goals (SDGs), such as socioeconomic improvements to health, education, communication infrastructure, gender equality, as well as economic opportunities in impoverished rural and urban settings (SE4ALL, 2017).

The Importance of Commitment

Countries' governments can take leading action and stimulate and steer energy transitions, and especially help breaking up with fossil fuel technology path dependency issues and lock-in effects (Stein, 2017). Path dependencies are said to emerge where past (investment) decisions, sunk costs associated with accumulated capital and experience or vested interests render the transition towards an alternative technology costly, i.e., they create a lock-in situation (Rosenbloom, 2019). In the context of energy transitions, these lock-in effects explain why already today we are observing scenarios where, even though more economic and beneficial technology is available, concrete action is slowed by what Sareen (2018) calls an "accountability crisis". Government's signalling comittment by proposing firm and ambitious renewable energy employment targets can counteract rigid path dependencies by providing a clear and transparent outlook of to be expected framework conditions, thereby ideally setting a clear horizon for outdated technology phase-out (driving disinvestment) and simultaneously providing guidance and orientation with respect to the roll-out of, and regulatroy support for, renewables. Renewable energy targets have become an important and popular component of countries' renewable energy deployment policies, with more than 160 countries globally having had adopted respective targets by 2015, and with targets comprising anything on a spectrum from publicly annoucned visions to legeally binding targets (IRENA, 2015b).

Commitment signalled by developing countries is especially pronounced, reflecting the acknowledgment of the development benefits renewabele energy development is proven to provide. In an analysis on global renewable energy targets comitted until 2015, IRENA (2015b) found developing and emerging countries to be most vocal about driving a stronger penetration of renewables in their energy systems.

1.2.2 Economic Drivers and Barriers

The Cost Advantage of Renewables: Driver Enough?

On paper, renewables are gaining the edge of their fossil fuel-based competitors with respect to technology economics and welfare gains. Levelized cost of electricity (LCOE) of renewable energy sources is following a downward trend, with especially solar PV and onshore wind already today proving more economic in some settings: Kost *et al.* (2018), in an analysis of the LCOE of different energy technologies in Germany in 2018, have provided evidence for the cost competitiveness of especially large-scale solar PV systems, both in northern and southern parts of Germany (see Figure 7). The authors further model the expected technology specific LCOE development up until 2035, finding the LCOE of solar PV systems to continue to fall, with even small solar PV systems becoming a more cost-effective technology solution as compared to newly installed hard coal and combined cycle gas turbine (CCGT) systems from 2025 onwards (Kost *et al.*, 2018). This narrative finds support also from elsewhere, with recent evidence available from the United States (EIA, 2020) and more generally for G20 countries (Ram *et al.*, 2017). When modelling the energy transition globally, the decline in technology costs of renewables (as well as storage technologies) is expected to significantly drive their deployment, with especially solar PV playing an important role (contributions of almost 70% to global electricity generation may be possible in 2050) (Breyer *et al.*, 2018). Cost reductions are a function of several interrelated factors, to which predominantly emerging economies of scale, international competition and the popularity of competition-driven policy instruments (such as auctions), technology improvements and efficiency gains, as well as low cost finance and funding are counting (Ajadi *et al.*, 2019). These factors are, however, context and geography dependent, and the LCOE can hence differ substantially from one country to another. As the next sections will show, grid parity remains out of reach for renewables where framework conditions are not conducive.

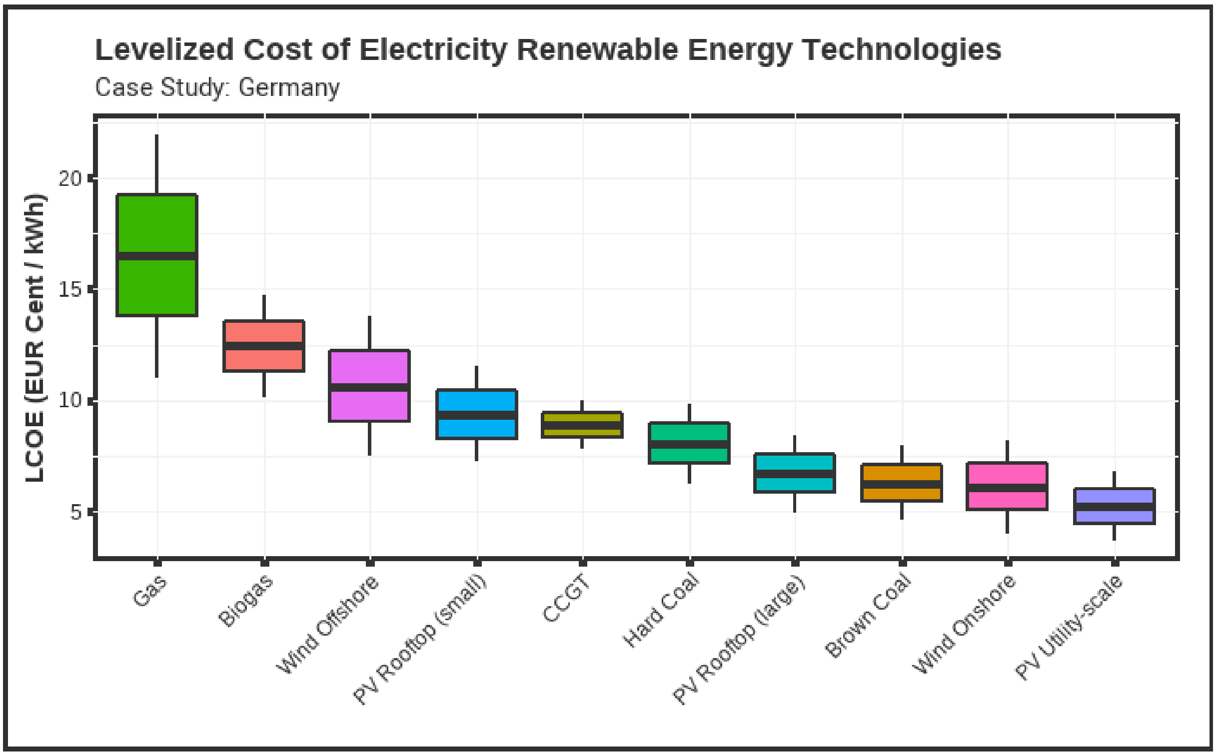


Figure 7: Levelized Cost of Electricity Renewable Energy Technologies, based on Kost et al. *(2018)*

High Cost of Capital: A Core Driver of LCOE

Even where no preferential treatment is distorting competition, renewables face significantly higher initial investment costs, i.e., the per MW cost of renewable energy assets is larger than the per MW cost of fossil fuel based alternatives (Beck and Martinot, 2004). The operation costs of renewable energy systems are much lower which may result in the competitive life-cycle costs of renewable energies, but the significantly higher initial investment needs drive up investors risk perception and remain a tremendous barrier to deployment, especially in developing countries. The cost of capital, measured as the weighted average cost of capital (WACC), comprises a significant component of the LCOE of renewable energy, ranging from for example 10% in Germany to 50% of LCOE in Brazil (Steffen, 2019). Research even suggests that the cost of capital across countries is a more significant determinant of the heterogeneity of cost competitiveness of renewable energy than renewable energy resource abundance (Ondraczek, Komendantova and Patt, 2015). The cost of capital is a function of the project developer's interest rate liabilities, and as such is directly influenced by the immaturity of financial markets in developing counties and project and context related risks, i.e., policy and regulatory risks, off-taker risks, grid access risks, currency risks, liquidity risks, resource availability risks and technology risks (IRENA, 2016). As a result, the high cost of capital, and through its impact on the LCOE of renewables, is especially a barrier to renewable energy deployment in developing countries where these risks are potentially more severe, rendering access to affordable finance a tremendous obstacle.

1.2.3 Social and Socioeconomic Drivers and Barriers

Social Acceptance Issues

Traditionally, taking a social perspective on energy transitions brings up especially one prominent theme: the social acceptance for renewable energy and its deployment. The lack of social acceptance can be a critical barrier to energy transitions and may delay or stop renewable energy project developments where groups with conflicting perceptions or interests formalize their political leverage. Prominently, Bell *et al.* (2013) have introduced the notion of the "social gap", which describes the apparent discrepancy between perceived public support for renewable deployment (wind in their original work, but applicable to most renewable energy technologies, according to the authors) and the significance of public opposition that project developers meet and often founder on. Wüstenhagen, Wolsink and Bürer (2007) offer a theoretic framework for understanding different forms of social acceptance and for the apparent discrepancy between a general notion of public endorsement and the remaining practical issues in establishing support for project implementation. The authors define "socio-political acceptance" for renewable energy deployment as the most general notion of public acceptance of the technology, and argue that the socio-political acceptance is relatively high in most countries (Wüstenhagen, Wolsink and Bürer, 2007). Further, the authors describe "community acceptance" and "market acceptance" as the acceptance constraints linked to procedural dimensions of deploying renewable energy technology, both from the perspective of local stakeholders (the prominent NIMBYism barrier, i.e., affected stakeholders may generally support renewable energy technology, but Not-In-My-Backyard), as well as with respect to technology diffusion in markets, and the role of producers and investors.

Social acceptance issues are not limited to developed countries only, although research on social opposition in emerging and developing countries remains limited. Survey evidence from Columbia suggests that it is especially the market acceptance dimension and the lack of the more general socio-political support which represent social barriers to renewable energy deployment in the country, and that deployment progress is only to a medium extent subject to community resistance (Rosso-Cerón and Kafarov, 2015). The NIMBYism theme seems not yet to be too pronounced in most developing country contexts, but more broadly issues of community acceptance, cultural consideration, land use competition, and most importantly, the lack of awareness of the potential benefits of renewable energy, are important social dimensions (González *et al.* (2016); Rosso-Cerón and Kafarov (2015), Hanger *et al.* (2016)).

With respect to decentralized renewable energy (DRE), social acceptance plays an especially important role. For those gaining access to electricity through DRE systems, the technology represents the initial personal gateway to modern energy service. However, for those living in impoverished rural or peri-urban contexts the financial burden imposed by the energy service provision is substantial and its net-benefit needs to be emphasized. Awareness of these benefits, as well as of the affordability of the technology, may be lacking, hence prohibiting optimal deployment of the technology through market means. On the other hand, even at cost-competitive prices, access to electricity may still be non-affordable for a significant number of disadvantaged households, and hence lead to a situation where markets cannot service these households, .i.e., what Navas-Sabater, Dymond and Juntunen (2002) refer to as the "access gap". Analyses conducted in rural Ethiopia for instance reveal that surveyed households' willingness to pay for electricity services does not yet suffice to recover connection costs (Entele, 2020). Evidence from Bangladesh presents an opposing picture, with estimated willingness-to-pay for decentralized renewable energy services elicited from rural households indicating the viability of sustainable electricity tariffs (Alam and Bhattacharyya, 2017). Clearly, context heterogeneity with respect to financial constraints affects social acceptability and capability to support (decentralized) renewable energy deployment, but it is also the misconception of the technology, its benefits and value, that distorts social acceptance. For example, evidence from rural India has shown that decentralized renewable energy systems may be perceived as over expensive, when their per kWh tariffs is compared to urban electricity tariffs that are substantially subsidised (Aklin, Cheng and Urpelainen, 2018), and Entele (2020) finds rural Ethiopian households' willingness-to-pay to be higher for grid connections than for decentralized systems, most likely due to ill-informed service level expectations.

Lack of Human Capital

A related and frequently neglected social barrier to renewable energy deployment is the lack of human capital, know-how, expertise and skilled personnel that is required to carry and promote the structural change associated with the emergence of a new sector (Seetharaman *et al.* (2019); Gabriel (2016)). The job generation potential of transitioning towards renewable energy is significant, but at the same time the education and training requirements for renewable energy sector professionals are specialized (Lucas, 2012). Where skilled labour is scarce, or professionals lack adequate training and required skills, the appropriate financing, marketing, deployment, operation, maintenance and decomposition of renewable energy technologies is impeded, i.e., the whole value chain is affected. It goes without saying that these challenges can be especially severe in developing countries, where education and training facilities may be less capable of rapidly adopting to the changing demands, or where not enough such facilities are available to rapidly build the required human capital.

1.2.4 *Technical Barriers to Renewable Energy Deployment*

Resource Availability

The availability of renewable energy resources is a precondition for the penetration of renewable energy technologies, and while not all resources are universally available (e.g., hydropower, geothermal and marine energy), fortunately other renewable energy resources, such as wind and solar irradiation, are globally available. Resource potentials, such as wind speeds and consistency or solar irradiance levels can be a determinant of renewable energy deployment, given that the abundance of the natural resource drives down the technology's LCOE. The resource potential of wind energy are significant in coastal areas (World Bank Group *et al.*, 2020), while in the global south solar irradiation levels make a case for solar PV technology deployment (World Bank Group, Solargis and ESMAP, 2020).

A much more limiting resource related to renewable energy technologies is available land, as well as the energy sector's (e.g., agriculture) competition with other sectors for this available land. Where only the generation asset is considered, in comparison to conventional generation capacity, renewable energy resources require extensive land area per unit of electricity generated (Seetharaman *et al.*, 2019). This may have detrimental effects on social acceptance (where people's backyards are affected, where natural habitat is being destroyed or where the siting of renewable energy projects interferes with indigenous group's land) and also drives up project costs. Bioenergy is especially land-intensive, followed by hydropower, solar CSP, solar PV and wind (Fritsche *et al.*, 2017). Land-use limitations may represent a potential barrier to energy transitions, especially in countries where land area is scarce and contested.

Grid Integration

Integrating large shares of variable renewable energy generation represents a challenge that can only be met by turning a country's energy system flexible, both on the demand and on the supply side (Martinot, 2016). The core challenge comprises balancing energy supply of which the renewable share is uncertain, with variable energy demand. The security of reliable energy supply is naturally the priority, but so is the optimization of system utilization in order to minimize costs. This is only achieved if a country's energy system can account for the variable electricity supply of renewables (i.e., in the night for solar PV, or when there is no wind for wind energy), for example via storage facilities, via reserve capacity of flexibly deployable conventional generation assets (i.e., gas, coal or diesel) or electricity imports. On the other hand, electricity generation at peak times often exceeds demand and grid capacity, rising the need to have adequate power supply curtailment provisions. This has impact on renewable energy project economics (Hwang, Kim and Ryu, 2019), and may represent a barrier to deployment where curtailment provisions are not efficient (such as through automation) (Bird, Cochran and Wang, 2014).

The need for curtailment due to congestion or failure is more severe in outdated or outgrown electricity grids. More generally, transmission and distribution assets in developing countries are often found to be incapable of physically integrating large shares of renewables. Especially in Africa, this is regarded as a major constraint to integrating higher shares of renewables (Ouedraogo, 2019).

1.2.5 Energy Transitions of Developing Countries: Where are the Differences?

The previous review of key barriers to renewable energy penetration comprises factors that affect both developed and developing countries, but they differ with respect to the extent to which they limit renewable energy deployment. Main constraints for driving forward the energy transition and increasing the share of renewables in the power-mix in developing countries comprise especially economic and financial barriers and inadequate policy landscapes and regulatory frameworks, as well as decaying infrastructure and lacking human capacities (Schmitz, 2015).

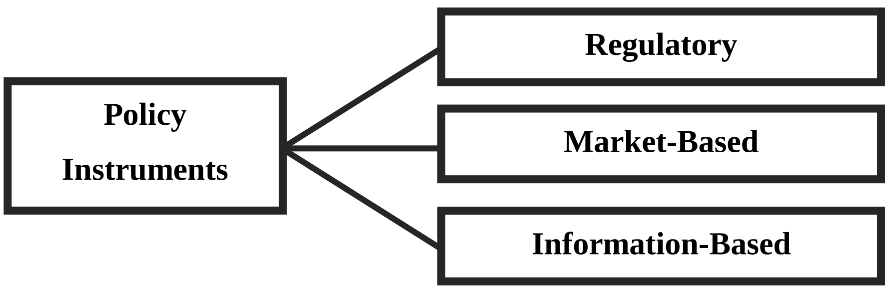
While the cost-competitiveness of renewables has resulted in the emergence of an endogenous driver of the energy transition in developed countries, the severity and intensity of above described barriers in developing countries continues to be prohibiting with respect to such dynamics (Spencer and Mathur, 2019). Significant effort remains to be required in order to render country frameworks favourable for scaled renewable energy penetration in developing countries, also and especially due to the great renewable energy resource potential available in the global south.

1.3 Policy Instruments for Renewable Energy Deployment Promotion in Developing Countries

1.3.1 A Framework of Policy Instruments

Governments around the global must take active stance in promoting their country's energy transition through rendering enabling frameworks conducive, as well as by taking measures to counteract country specific deployment barriers. For developing countries, this is even more so important, but for countries characterized by weak institutional capacity and ineffective governance structures, this is even more so challenging.

Park (2015) offers a simple trifold typology that summarizes the main set of policy tools governments have on their disposal:



Regulatory policy instruments comprise means that directly or indirectly alter the regulatory realities of renewable energy, or that increase the attractiveness of renewable energy viz-a-viz conventional generation systems. This may comprise the establishment of renewable energy mandates (i.e., any form of obligation on minimum share of renewable energy), codes and standards, grid access rules (such as net metering for small scale systems or priority dispatch rules for large scale renewable energy) or licencing provisions (Benitez (2012); Park (2015).

Market-based instruments, on the other hand, rely on the basic premise that governments can alter the utility pay-off functions of different scenarios such that the one perceived as optimal is preferred by affected stakeholders. They may comprise quantity instruments such as Renewable Energy Purchase Obligations or Renewable Energy Certificates (REC), which represent tradable commodities electricity generators obtain for each unit (usually per MWh) of electricity produced. RECs represent the clean energy attributes of electricity generated from renewable energy. Besides quantity instruments, market-based instruments of relevance for the developing country context primarily encompass means of providing cost advantages to renewable energy generators, for example through incentive structures or preferential tariff schemes (Benitez, 2012).

Information-based instruments predominantly refer to measures aimed at responding to capacity needs or awareness raising requirements in order to avoid information asymmetries that may impede the deployment of renewable energy technology (Park, 2015). Where aimed at raising awareness of the benefits or affordability of renewable energy, these are also especially important to respond to social acceptance and innovation diffusion issues as discussed in Section 1.2.3. They can be of significant relevance for addressing barriers discussed in Section 1.2, where aimed at driving human capital development, innovation and even R&D.

Feed-In Tariffs for Cost-Competitive Renewables

Feed-in tariffs (FIT) are a popular market-based approach to supporting the expansion of renewable energy generation in a country. With FITs

, the clean electricity producer receives guaranteed grid access and is sure to market all of its generated electricity. Further, the generator receives either a fixed renumeration per generated unit of electricity or a fixed or variable premium in relation to the market price in the electricity market (sliding premium, or Contract for Differences, CfD) (Ringel, 2006). Feed-in tariffs are found to have successfully attracted investment into renewable energy capacity in some regions (Wall *et al.*, 2019), but have been less successful in driving project development for example in Sub-Saharan Africa (Eberhard *et al.*, 2016). Administratively setting the right support level of FITs is difficult, may be inefficient, and does not provide governments much control over quantity, i.e., capacity of renewable energy, as would for example be the case with quantity-based instruments as discussed before.

Renewable energy auctions represent a prominent advancement on this issue, representing a hybridisation of market-based and quantity-based instruments in that both quantity and prices are determined through a competitive bidding process, while governments remain in control over budgetary expenses and / or total capacity deployment (IRENA, 2015a).

1.3.2 *Auctions as the Silver Bullet?*

Renewable energy auctions have emerged as an extremely popular policy instrument for governments to primarily provide economic incentives for renewable energy deployment and recently also increasingly to respond to deployment barriers not directly related to renewables price competitiveness.

Renewable energy auctions are a means of renewable energy capacity (MW), electricity generation (MWh), or electricity service (for example, connections) procurement. Auction based procurement employs a competitive bidding process to determine primarily the volume and price of the auctioned product to be deployed in a specified period, but that may further extend to for example reveal optimal location or technology options (Mora Alvarez *et al.*, 2017). In standard auction processes, project developers would bid the lowest level of price or support they would require to develop renewable energy assets, and typically the project developer with the lowest price or support needs is awarded the contract, and with it a power-purchasing-agreement (PPA) or price premiums / support. The argument in favour for auction based procurement of renewable energy is (i) the competition-driven price revelation mechanism that allows for efficient allocation of support, and (ii) the government's ability to non-discriminately control the volume and pace of renewable energy deployment (through capacity or budget constraints) (Mora Alvarez *et al.*, 2017).

Renewable energy auctions have gained significant popularity over recent years, which is not least due to their international track record of leveraging significant investment for renewable energy capacity and driving down prices. Globally, awarded weighted average prices of for solar PV and onshore wind have fallen from 250 USD per MWh and 75 USD per MWh respectively in 2010 to close to 50 USD per MWh for both technologies in 2018 (note that this represents global averages and that in some countries' auctions have yielded substantially lower prices) (IRENA, 2019b). In 2018 alone, auction-based procurement led to additional capacity of almost 60 GW of solar PV and about 40 GW of onshore wind, representing almost 90% of all auctioned capacity in that year (IRENA, 2019b). Experience with auctions in South and East Asia is growing, but also in Sub-Saharan Africa auctions increasingly build up reputation for their ability to attracted much needed private investment, as well as for their adaptability to specific country contexts (IRENA, 2019b).

Advantages and Disadvantages of Auctions

For developing countries, renewable energy auctions can represent a compelling policy option. They eliminate off-taker risk (to the extent that the government or utility do not default) and ensure that project developers can market generated electricity at profitable and stable prices (i.e., provided through long-term PPAs). The auction itself also regulates, and where necessary, facilitates the market access for international companies, should they be successful in the auction (Keeley and Matsumoto, 2018).

From an economic perspective, developing countries must critically reduce electricity prices in order to facilitate economic growth and to ensure that electricity service provision leaves no one behind. The competitive pressure exerted on electricity prices in auction processes seems to cater to this need effectively. Experiences from South Africa’s Renewable Energy Independent Power Procurement Programme (REIPPP) auction indicate, that the low price level of electricity tariffs obtained through the auction has been unmet by administratively feed-in schemes in the country (Eberhard and Kåberger, 2016). Similar trends have been observed also more broadly in Sub-Saharan Africa, such as in Uganda and Zambia, according to (Kruger and Eberhard, 2018).

Importantly, renewable energy auctions are increasingly designed to also cater to secondary policy objectives, i.e., objectives besides competitively procuring power or capacity at efficient price levels. Theoretically, this bears the advantage for policy makers in developing countries to deploy a one-for-all policy that tackles several renewable energy deployment and context barriers at the same time. Through the incorporation of distinctive design elements, auction mechanisms may be altered to, for example, ensure the security and diversity of supply (Kitzing *et al.*, 2016), promote the development of local value chains and industries, give preferential treatment to certain actor types, influence geographical distribution of renewable energy projects (and hence benefits or costs), facilitate seamless integration of variable generation technologies (Simone Steinhilber; Emilie Rosenlund, 2016), foster local research and development capacities (Sarı, Saygın and Lucas, 2019), as well as establish frameworks for a just and inclusive energy transition more generally (IRENA, 2019b).

A disadvantage of renewable energy auctions is their tendency to be complex and hence subject to significant administrative and transaction costs (Hawila, Lucas and Ferroukhi, 2013). Secondary objectives, such as those discussed above, are likely to render auctions more complex, increasing the cost to project developers and naturally leading to higher electricity prices. Further, administrative barriers and qualification requirements imposed in auctions are found to discriminate against the participation of certain actor groups, such as for example small actors who lack capacity or resources to comply with strict material or financial requirements (Fell, 2017). These actor groups, or more generally auctions conducted in immature markets, require special consideration (IRENA, 2015a), especially in developing countries.

Auctions are also criticized for being too government-centric, in that volume, technology, and frequency of procurement is fully in the hands of the auction conducting government (Fell, 2017). Where a countries' administration changes, and with it the political goodwill for renewable energy deployment, auction schemes may be discontinued or bid rounds may be delayed, resulting in additional layers of project risks and project pipelines and development cycles that are difficult to anticipate, especially in developing countries facing weak institutions and governance structures (see for example Menzies, Marquardt and Spieler (2019) for a discussion of the Argentine case) .

Design Elements of Auctions: An Overview

Auctions are a flexible renewable energy support policy, and hence well adaptable to specific country contexts. The ability to further cater to a wider range of secondary objectives can be a significant benefit for policymakers that seek to effectively respond to multiple renewable energy deployment barriers simultaneously. The way this is achieved through auctions is via the right composition of adequate design elements. Best practices for the design of auctions has attracted significant scholarly interest and remains to be an academic field that certainly benefits from future research. The following table provides an general overview over the most important design elements of renewable energy auctions relevant to developing country context, while a more comprehensive discussion is provided by Mora Alvarez *et al.* (2017) and Del Río *et al.* (2015).

Table 1: Adapted from IRENA (2015a), Mora Alvarez et al. (2017) and Del Río et al. (2015)

Design Element	**Description**
Technology Diversity	Technology-specific auctions: In technology-specific auctions, bidders are not competing across technologies, but only in technology-specific bands. Technology-neutral auctions: In technology-neutral auctions, all technologies compete with each other, irrespective of asymmetric generation cost structures.
Volume	Target volume: Capacity, support budget (or alternative volume metrics such as number of connections) that is targeted, i.e., that shall be developed or used.
Location Constraints	Restrictions on geographical siting of projects, or the use of locational correction factors to influence siting.
Type of Remuneration	Successful projects are remunerated based on the electricity they generate (per MWh) or for the capacity they add (per MW). Remuneration in an auction can be provided for generation (MWh) or capacity (MW). Remuneration per MWh may comprise full payment (FIT) or be provided in the form of a fixed or variable premium top-up on the market price (FIP / CfD).
Selection Criteria	Price-only auctions: The winning bidder is determined solely based on bid price. Multi-criteria auctions: The winning project is determined based on both price and additional criteria (for example the share of local content).
Auction Format	Single-item auction: The item that is auctioned is a non-divisible single project that will be developed by a single bidder (for example where capacity is to be developed on a pre-defined site or where there have been pre-developments on a project).

	Multi-item auctions: Usually, in auctions bidders are competing for a divisible good (i.e., a targeted capacity), such that multiple bidders may be awarded to construct different projects towards the targeted capacity.
Auction Type	Static auction (sealed bid): In a static auction process, undisclosed bids are ranked in descending price order. From the top, all projects are awarded PPAs until the targeted capacity is reached. Dynamic auction (descending clock): In a dynamic auction process, the conducting entity is progressively announcing lower price levels (over multiple rounds) until the capacity offered by bidders matches the capacity targeted in the auction. Hybrid formats: A mix of approaches, whereby usually the process starts dynamically and subsequently a sealed bid process is adopted.
Pricing Rule	Pay-as-bid (PAB): Successful bidders are remunerated their bid. Uniform pricing: All successful bidders receive a uniform price, which is determined either by the highest but successful bid, or the lowest but unsuccessful bid.
Price Limits	In order to ensure that the support for the targeted capacity does not exceed budgeted resources, technology specific price limits may be used.
Periodicity	The existence of pre-defined schedules or plans with respect to the implementation of auction rounds.
Prequalification Requirements	Restrictions: Only bidders can qualify that adhere to certain restrictions on technology, level of project development experience, size or type. Financial: Only bidders can qualify that can prove financial strengths, i.e., for example through the issuance of bid-bonds.

	Material: Only bidders can qualify that can provide evidence of material requirements, such as licenses, land rights, environmental approvals, etc.
Penalties for non-compliance	Penalties for non-compliance or delay, for example in the form of ban, support level cuts, or support period reduction.

As summary, recently renewable energy auctions have emerged as an extremely popular policy instrument for governments to primarily provide economic incentives for renewable energy deployment. From an economic perspective, developing countries must critically reduce electricity prices in order to facilitate economic growth and to ensure that electricity service provision leaves no one behind. The competitive pressure exerted on electricity prices in auction processes seems to cater to this need effectively. Nevertheless, auctions do not work in isolation and need an enabling environment (market capacity, institutional capacity, energy infrastructure, etc.) and they design elements have to be carefully chosen case by case.

1.4 Objectives

Driving forward the global energy transition represents a tremendous challenge that crucially depends on unified efforts of the global community to leave no one behind. This is essential given the irrelevance of boarders and nations when it comes to climate change mitigation, and it is essential due to the importance of knowledge and technology transfer for the protection of the common good. This implies the need of directing scholarly attention to:

- The specific challenges that developing countries are facing with respect to promoting stronger renewable energy penetration.
- The viability and benefits of adapting good practice and concept-proven policy instruments to the contexts of developing countries.
- Highlight where contemporary approaches are failing to overcome those barriers that continue to widen the energy transition discrepancy we are facing today.

It is the objective of this thesis to contribute to this scholarly discourse, by providing original analyses of the barriers to renewable energy deployment based on an evaluation of the Pacific Small Island Developing States context, by exploring human capacity shortages and inadequate capacity building programmes as an example of a complex and neglected barrier to energy transitions globally and even more so in developing countries, by analysing auction mechanisms for their alleged capability of driving down electricity prices (which helps with affordability concerns in developing countries) in the context of Sub-Saharan Africa, and by extending the analysis of renewable energy procurement auctions also to the context of rural electrification needs in Peru.

In this way, this thesis seeks to build understanding of where and how auctions as a contemporary popular and promising policy instruments can be adapted to the developing country context, but also where even the flexibility and adaptability of auctions are insufficient and a broader policy mix is needed.

1.5 Thesis Structure

The thesis follows a structure that connects different arguments to arrive at an integrate evaluation in line with the objective stated above. Following the introduction to the status of the energy transition, the role of the energy transition in developing countries, a broad literature review of the most common barriers to renewable energy deployment, as well as an introduction to the popularity, relevance and design elements of auctions provided in Chapter 1, four published papers, as well as their role for this thesis, are being presented in Chapter 2 to Chapter 5. Finally, Chapter 6 concludes, as well as recommends pathways for further research.

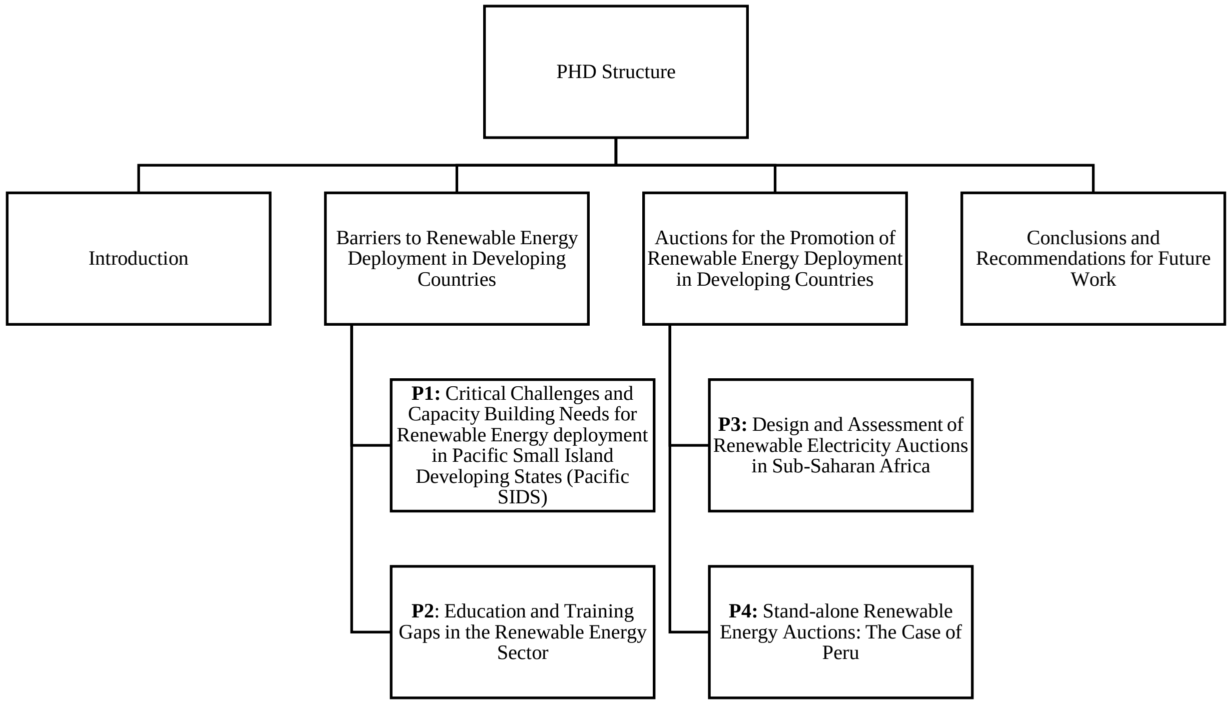


Figure 8: Graphical Representation of Thesis Structure

Chapter 2: Critical challenges and capacity building needs for renewable energy deployment in Pacific Small Island Developing States (Pacific SIDS)

2.1 Introduction

Chapter 1 has provided some first notion of how the general topology of barriers to renewable energy deployment that applies in all countries may be especially severe in developing countries, especially along regulatory / political and economic dimensions. The intensity and prevalence of existing barriers, as well as their specific functioning in contexts characterised by high vulnerability and / or low human development, must however be better understood. This represents a vital premise for the design of effective support mechanisms that will allow affected countries to advance renewable energy deployment and to reap the economic and social benefits.

To advance the academic discourse on the critical challenges to renewable energy penetration in developing countries, a in depth analysis of the status and barriers to renewable energy deployment on Pacific Small Island Developing States (SIDS) was conducted, given the SIDS' high level of vulnerability and in order to explore the specific barriers imposed for energy transitions in island settings. The paper was published as below:

> Lucas, H. *et al.* (2017) 'Critical challenges and capacity building needs for renewable energy deployment in Pacific Small Island Developing States (Pacific SIDS)', *Renewable Energy*, 107, pp. 42–52. doi: 10.1016/j.renene.2017.01.029.

2.2 Contribution to State-of-the-Art

Prior to the publication of Lucas *et al.* (2017) the topic of renewable energy deployment in Pacific SIDS had received some academic attention, but no comprehensive assessment of prevalent barriers had been conducted. An early assessment of the potential and benefits of renewable energy generation on SIDS is provided by Weisser (2004), who also takes note of the policy-related shortcomings in the region that affect renewable energy proliferation, but who also urges for more comprehensive and holistic research on the matter. Further analysis was conducted by Urmee, Harries and Schlapfer (2009), on the barriers for renewables in Asia and the Pacific, but little reference was provided to those specific factors that hinder deployment progress in island contexts. Finally, Kuang *et al.* (2016) had provided a comprehensive analysis focussing on the status of renewable energy utilization in island states, but with no specific focus on the barriers imposed.

Lucas *et al.* (2017) constitutes an original contribution to the analysis of the unique situation of Pacific SIDS with respect to their energy transitions, based on a comprehensive survey among the main stakeholders in the region. The significant dependence of costly and price-volatile fossil fuels (especially diesel) has been identified as a detrimental factor to economic growth for many Pacific SIDS. To this end, energy security is a major concern in the region, but also with respect to ensuring the provision of universal electricity access, which remains extremely low for some island states, e.g., Papua New Guinea, in the Solomon Islands, or in Vanuatu. Most governments of SIDS show acknowledgement for the benefits of (decentralized) renewable energy solutions, have put forward ambitious targets and have initiated early policy measures. At the same time, however, the region faces several challenges that are in part unique to the island context and in part typical for developing countries.

The study followed the objective to (i) identify these characteristic barriers to renewable energy deployment in the region, but also (ii) sought to produce recommendations on how they may be overcome, as well as (iii) offered a qualitative assessment of their relative importance.

With respect to the identified challenges, the lack of renewable energy data was found to critically limit informed policy making in the region, which demands more streamlined data collection and resource assessment efforts integrated into policy planning. Established policy and regulation measures were also found to be often ineffective and in transparent, and further fail to effectively cater to objectives beyond market deployment. Greater public guidance and a clear direction is required from governments, that allows for formalizing the regulatory landscape of countries' efforts towards reaching renewable energy penetration targets. Importantly, the ineffective policy landscape, as well as the inability of local financial infrastructures to adequately respond to financing needs, was found to be significantly driven by lacking expertise and know-how in the region. Private finance was found to be especially scarce, calling for a review of how independent power producers and investors may be attracted (i.e., through incentivizing PPAs). This is however hampered by human capacity shortcomings that are especially prevalent with respect to finance know-how, but also more generally a lack of skilled human resources was found to be an important barrier to the deployment and operation and maintenance of renewable energy generation assets in the region, highlighting the significant need of capacity building programmes for all involved stakeholders. Lucas *et al.* (2017) also provide evidence of social opposition to the structural change of the status quo that the aspired energy transitions are accompanied by, and urge for the consideration and reflectance of social acceptance dimensions through the integration of local stakeholders in the planning and implementation of renewable energy projects, as well as awareness raising more generally. Finally, due to the lack of economies of scale with respect to infrastructure development in small islands, the lack of modern infrastructure was found to be a critical barrier to the deployment of centralized large-scale renewable energy generation assets.

2.3 Journal Paper

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Critical challenges and capacity building needs for renewable energy deployment in Pacific Small Island Developing States (Pacific SIDS)

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Capacity building

A B S T R A C T

The Pacific Small Island Developing States (SIDS) are among the most vulnerable to the impacts of climate change. Besides, they are some of the most dependent on imported petroleum products in the world, the use of renewable energy (RE) can help minimize the economic risk associated with the price volatility of fossil fuels. The region is increasingly adopting renewable energy (RE) targets and policies. Successful examples of RE deployment in the Pacific SIDS exist; however, many barriers persist and prevent the use of the region's RE resources in a larger scale. Challenges for RE deployment in islands can be grouped in six categories: i) lack of RE data, ii) need for policy and regulatory frameworks, iii) scarcity of financial opportunities, iv) lack of human resources, v) costly infrastructure, and vi) socio-cultural impediments. Based on a survey conducted among main stakeholders in the region, within the framework of the Pacific Region Capacity Building Initiative of the International Renewable Energy Agency (IRENA) carried out in cooperation with the Secretariat of the Pacific Community (SPC), this paper identifies the specific characteristics of these challenges in the context of the Pacific SIDS, provide a qualitative assessment and identifies recommendations to overcome these challenges.

Chapter 3: Education and Training Gaps in the Renewable Energy Sector

3.1 Introduction

The importance of the human capacity barrier identified in Lucas *et al.'s* (2017) analysis of the Pacific SIDS' barriers to renewable energy deployment is significant, and it is more than likely relevant also to energy transitions of developing countries in other regions, as well as more generally on a global level. This is not surprising, given the aspired scale and pace of the global energy transition and the structural disruption of economies, and the energy sector specifically, that must be associated with this transition.

Perceived human capacity shortcomings are inherently difficult to assess, as they are intangible and as such difficult to quantify. To advance the academic discourse on human capacity needs for advancing the renewable energy transition in developing countries, a comprehensive assessment of education and training gaps in the energy sector was conducted. The difficulty of obtaining data on education and training gaps in developing countries, where renewable energy sectors are often still in their infancy, only allowed for an evaluation of these human capacity deficits on a global scale. Nevertheless, it can be firmly argued that the prevalence of capacity deficits on the global level can be regarded as a conservative representation of the barriers that also developing countries are facing. The paper was published as below:

> Lucas, H., Pinnington, S. and Cabeza, L. F. (2018) 'Education and training gaps in the renewable energy sector', *Solar Energy*. Elsevier, 173(July), pp. 449–455. doi: 10.1016/j.solener.2018.07.061.

3.2 Contribution to State-of-the-Art

Targeted academic literature on capacity needs and education and training requirements for advancing energy transitions is only just emerging. Insufficient human capacity as a barrier to renewable energy deployment is however frequently mentioned by scholars, also and especially in developing country contexts. At the time of publication, examples comprised Karekezi's (2002) analysis of the renewable energy needs in Africa, Ansari *et al.'s* (2013) reference to lacking training facilities and skilled personnel for solar PV development in India, as well as Karakaya and Sriwannawit's (2015) concerns with respect to a inadequately trained work force's effect on solar PV deployment for developed and developing countries. Human capacity deficits need to be overcome through comprehensive education and training programmes, a stance that is prominently promoted by Kandpal and Broman (2014) and Kandpal and Broman (2015). Lucas, Pinnington and Cabeza (2018) build on these groundworks and provide a novel and comprehensive assessment of the current renewable energy education and training supply, based on data obtained from IRENA's Renewable Energy Learning Partnership (IRELP) database.

Lucas, Pinnington and Cabeza (2018) find the pace at which the energy transition requires the structural adaptation of energy sectors to represent a challenge for renewable energy education and training providers to supply respective educational offer that is of relevance, especially due to significantly different requirements on renewable energy professionals as opposed to the work force employed in the conventional energy sector. This represents a barrier to renewable energy deployment and further places the quality and efficient utilization of renewable energy technology under risk, which is especially a concern where these technologies are still in their proof-of-concept phase (for example for innovative decentralized renewable energy systems as rolled out in rural areas). It is found that the renewable energy industry is in significant demand for very specialised professions with relevant training for different technologies, but also with broader knowledge of previously secondary concepts, such as among the themes of environmental protection, sustainability and economics. These industry demands are found to be inadequately matched by education providers.

A novel contribution provided through Lucas, Pinnington and Cabeza (2018) is its analysis of the training offer published on IRENA's Renewable Energy Learning Partnership (IRELP) database, as well as website traffic recorded. This has allowed to portray the type, topic, and technology, as well as geographical distribution of the available course offer. The analysis of the website is substituted with interview-sourced insights from industry stakeholders, singling the capacity shortages they are facing and the training and skill levels they are interested in. An important finding is the apparent demand for highly specialized professionals, which the education sector fails to provide given their predominant offer of multi-technology / general courses. Further, it was found that both the education offers as well as the apparent mismatch are especially severe in developing countries and primarily in Africa. This is a concerning finding, because Lucas, Pinnington and Cabeza (2018) also show that there seems to be significant interest for courses coming from database users from Asia and Africa, as measured through website traffic tracking.

Strengthening efforts to roll out renewable energy education and training programmes will be pivotal for facilitating unhampered energy transitions, globally and especially in disadvantaged developing countries. The analysis shows that quality and quantity of education offer are both of significant importance. The lack of skilled personnel represents a complex barrier, and significant research is required for developing streamlined policy responses.

3.3 Journal Paper

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ELSEVIER

Education and training gaps in the renewable energy sector

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ABSTRACT

One of the barriers to achieve the expected renewable energy market development is the shortage of qualified human resources. Global data on education and training on renewable energies was analyzed in order to gain an understanding of the current education supply worldwide. Findings are: (i) the shortage is more acute in developing countries; (ii) there is a mismatch between education system offer and industry demand; (iii) there is also a mismatch in the suitability of the curricula; (iv) students and educators are moving towards online training for collaborating and learning. While it remains a challenge to increase, improve, and facilitate access to renewable energy education and training, the high interest of females in renewable energy education represents an opportunity to counter the scarcity of professionals in the sector.

Chapter 4: Design and Assessment of Renewable Electricity Auctions in Sub-Saharan Africa

4.1 Introduction

Section 1.3.2 has provided an introduction for why and how renewable energy auctions may comprise an effective and efficient policy instrument for promoting renewable energy penetration globally and in developing country contexts. The ability of policy makers to deploy well designed auction mechanisms for procuring renewable energy capacity at very competitive prices is a primary benefit, but also auction's capability to cater to secondary objectives and help overcoming prevalent barriers to renewable energy deployment in developing countries, such as identified in Lucas *et al.* (2017), is important. Also with respect to the specific human capacity barrier as discussed in Lucas, Pinnington and Cabeza (2018), auctions provide options for targeted intervention (see for example Sarı, Saygın and Lucas' (2019) analysis of the Turkish YEKA auction scheme).

To advance the scholarly discourse on the viability of auction mechanisms to respond to developing countries' renewable energy promotion challenges, a comprehensive analysis of the design and assessment of renewable electricity auctions in Sub-Saharan Africa was conducted. While efforts to deploy auction are gaining traction in developing countries and also in Sub-Saharan Africa, challenges for effective renewable energy deployment remain. The portrayal of auctions as a panacea for renewable energy transition promotion has to be critically discussed, and the need for supplementary policy effort (for example to respond to structural barriers such as human capacity deficits as laid out in Lucas, Pinnington and Cabeza (2018)) must not be underestimated. The paper was published as below:

> Lucas, H., del Rio, P. and Sokona, M. Y. (2017) 'Design and Assessment of Renewable Electricity Auctions in Sub-Saharan Africa', *IDS Bulletin*, 48(5).

4.2 Contribution to State-of-the-Art

Efforts to move away from administratively set support schemes for renewable energy have only recently gained traction in Sub-Saharan Africa, with South Africa representing the front runner since 2011 to this end. Prior to the publication of Lucas, del Rio and Sokona (2017), auction schemes in Sub-Saharan Africa have received little attention in the academic literature.

Eberhard and Kåberger (2016) had at that time only offered insights on the South African REIPPP auction scheme but had built evidence for its relevance for cost minimization. Azuela *et al.* (2014) had further contributed an analysis of renewable energy auction performance experiences from Brazil, China, and India. With a more general focus on auctions in developing countries globally, Hawila, Lucas and Ferroukhi (2013) have provided early groundwork for the subsequently growing interest in renewable energy auctions in developing countries.

The analysis conducted was motivated by renewable energy auction's promise to deliver renewable energy deployment in a cost-effective manner and at scale in Sub-Saharan Africa, given the initial convincing experience from South Africa and abroad. Lucas, del Rio and Sokona (2017) however argue, that the design of auction in developing country contexts and more specifically in Sub-Saharan Africa requires close attention, given that some of the barriers, and the severity of which, are unique to the region.

Lucas, del Rio and Sokona (2017) find energy security to be a significant motivator for renewable energy deployment in the region, but highlight the prevalence of especially economic / financial, regulatory / political and technical barriers, as well as the apparent inability of administratively set FITs to effectively leverage private investment into renewable energy capacity in the region. Research was conducted based on literature reviews and interviews with key stakeholders from the three focus countries of the study: Uganda, Zambia and Ghana. The focus countries provide interesting insights into the functioning of auction systems in countries facing heterogeneous contexts, with respect to transmission asset quality, socioeconomic conditions, electricity consumption and electricity access rates.

Lucas, del Rio and Sokona (2017) find renewable energy auctions to be an effective means of promoting deployment in Sub-Saharan Africa, finding them to be successfully addressing some of the economic and technological barriers prevalent in the analysed developing countries. Importantly, however, it is found that auctions' success is also a function of donor's technical assistance and the establishment of favourable enabling environments, referring also to human and institutional capacities and capabilities. As such, auctions cannot be relied on as a sole policy instrument to promote energy transitions in developing countries, but it is instead only a comprehensive and aligned mix of policies that can cater to the need of mainstreaming far-reaching structural change.

4.3 Journal Paper

Institute of Development Studies | **bulletin.ids.ac.uk**

Design and Assessment of Renewable Electricity Auctions in Sub-Saharan Africa

Hugo Lucas,[1] Pablo del Río[2] and Mohamed Youba Sokona[3]

Abstract Auctions have recently been regarded as a useful alternative to other support schemes for setting the remuneration of renewable electricity (RES-E) worldwide. They have also been increasingly adopted in the sub-Saharan Africa (SSA) region, mostly due to their promise to support the deployment of RES-E projects cost-effectively. The aim of this article is to identify the design elements of RES-E auctions in SSA and assess their pros and cons with respect to different criteria. The results show that the design elements adopted in the SSA auctions are similar to other countries, but some design elements are deemed very relevant in order to address specific constraints to RES-E investments in SSA countries, including pre-selection of sites, technology-specific (solar PV), and price-only auctions. However, the main distinctive feature of auctions in SSA is that they are part of a broader policy mix of support mechanisms aimed at de-risking and providing technical support.

Chapter 5: Stand-alone Renewable Energy Auctions: The Case of Peru

5.1 Introduction

Section 1.2.1 has laid out how the discussion of energy security in the context of developing countries is also and especially a discussion of energy access provision, given the importance of energy access for socioeconomic development and economic growth. Decentralized renewable energy technology, such as solar PV stand-alone systems or mini-grids, can be instrumental for developing countries facing energy access gaps, and is already being successfully deployed via private and public-private initiatives in many parts of the world. The challenges countries are facing with respect to achieving universal electrification are unique, comprising economic and financial barriers on the supply side, but also social acceptance and affordability constraints on the demand side. On the other hand, decentral deployment of small-scale renewable energy systems bears opportunities for addressing transmission grid integration barriers and generally renders countries' energy systems more resilient.

The complexity of auctions can be quoted as a central limitation to its success in immature markets or for niche technology promotion (IRENA, 2015a). However, recent experiences with auctions for the procurement of electrification services (as opposed to capacity or generation) provide additional evidence for the flexibility with which auction mechanisms may be deployed, also for the objective of ensuring access provision in developing countries. To advance the scholarly discourse on the use of auctions for this important dimension of energy security in developing countries, the experiences Peru had made with its stand-alone renewable energy auctions were evaluated. This analysis was published as follows:

> Lucas, H., del Río, P. and Cabeza, L. F. (2020) 'Stand-alone renewable energy auctions: The case of Peru', *Energy for Sustainable Development*. International Energy Initiative, 55, pp. 151–160. doi: 10.1016/j.esd.2020.01.009.

5.2 Contribution to State-of-the-Art

The academic literature on the use of auction mechanisms for the procurement of small-scale renewable energy systems for the electrification of rural areas remains scarce to date. However, in fact several attempts at implementing auctions in the context of electricity access and mini-grids are recorded, for example in Nigeria, Rwanda, Sierra Leone, Mali and Indonesia (IRENA, 2018). Most significant academic interest was so far raised by Nigeria's solar PV plus storage reverse auctions in the context of energy access, for example by Arowolo (2019) and Arowolo *et al.*, (2019).

What sets the analysed auctions in the context of Peru (and also in Mali) apart is its focus on stand-alone solar PV systems. The volume metric procured in Peru constituted a minimum of to be established electricity connections through the deployment of stand-alone solar PV systems, as opposed to traditional generation or capacity targets. Peru's motivation for deploying the scheme has been the private sector's inability to provide decentralized renewable energy services levels due to affordability constraints of poor households in rural areas (grid extension was financially not viable). The auction aimed at incentivizing the private sector to close the country's small but persisting access gap.

The analysis of the Peru case study conducted in Lucas, del Río and Cabeza (2020) is based on a review of policy documents and semi-structured interviews with main stakeholders involved in the auction process. A central finding is the that the success of auction mechanisms aimed at the procurement of electrification services crucially depends on a diligent choice of design elements, starting with a well-considered but flexible approach to setting the volume of energy service that is auctioned. In the case of Peru, the product auctioned was defined as the number of connections, while the actual number of connections that was targeted only represented an estimated minimum, but secured with a cap. Of special importance are also provisions for controlling the geographical distribution of the deployment of systems, notably under the consideration fairness and social acceptance. It has also been found that measures to value the service levels provided by deployed systems, such as correction factors, are important where the auctioned metric does not automatically take them into account. Finally, the experience in Peru has confirmed that the suitability of auctions for nascent application such as context-specific electrification service provision depend on the extent to which they can attract enough competition in the auction process and / or avoid discriminating against smaller actors who cannot draw on significant economies of scale.

5.3 Journal Paper

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Stand-alone renewable energy auctions: The case of Peru

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ABSTRACT

Electrification policies are crucial to improve the welfare of rural populations worldwide. In this context, auctions for the deployment of stand-alone solar home systems (SASHS) are an appropriate alternative to facilitate access to electricity in rural areas. The aim of this paper is to analyze the design elements and functioning of the SASHS auction in Peru in order to derive lessons for the effective and efficient design of those auctions. Based on an analytical framework developed elsewhere, this article draws on official documents and data, secondary material and interviews with stakeholders. Our results show that some design elements are particularly suitable in this regard. In contrast to renewable electricity auctions in general, for which the volume auctioned is usually set as capacity (MW) or generation (MWh), the volume of SASHS auctions should be set in terms of the number of SASHS providing an electricity service. Geographical diversity, with different auctions per region, would ensure the adoption of a minimum amount of SASHS in a given geographical area. Financial solvency, but not technical reputation, should be required. Otherwise, only the incumbents would be able to participate in the auction. The choice of technology-specific, price-only, sealed-bid, single-item auctions brings benefits in terms of economies of scale, lower support or transaction costs and a greater transparency or simplicity. A correction factor on the remuneration which accounts for the quality of the service, as applied in the Peru auction, is suitable for this type of auctions. Finally, provision of technical information, which facilitates the participation in the auction, and the implementation of a non-disclosed ceiling price are deemed appropriate. In contrast, given the low presence of local companies in the Peruvian PV market, the adoption of local content requirements would lead to higher support costs without significantly increasing the local development potential.

Chapter 6: Conclusions and Recommendations for Future Work

The global energy transition poses a tremendous challenge to all countries worldwide, but especially to developing countries. Developing countries face the dual challenge of having to contribute their share to climate change mitigation while simultaneously trying to urgently promote sustainable development. Given that the latter is critically driving up energy demand, the former can only be achieved when developing countries manage to decarbonise their power sectors.

This thesis has shown, that from a security of supply perspective, as well as from an economic perspective, developing countries have huge interest in promoting energy transitions, and where possible even leapfrog or avoid fossil fuel entry completely. From a human development perspective, decentralisation of renewable energy generation through the deployment of small-scale generation systems further represents the most viable and cost-effective approach for reaching scale in rural electricity access provision, which is expected to be accompanied by a tremendous sustainable development dividend (SE4ALL, 2017).

Renewable energy technology costs are falling globally, with some countries achieving grid parity due to the competitive LCOE of especially solar PV and wind generation technologies in countries with low cost of capital. Barriers to renewable energy deployment for developing countries, however, remain significant, even though renewable energy resource potentials are immense. Given the inherent complexity associated with the structural change implied by energy transitions, barriers spanning regulatory / political, economic, social and technical dimensions also persist in developed countries, but the deployment momentum that the cost-competitiveness of renewables is spurring in developed countries cannot yet be replicated in developing countries due to the higher significance and prevalence of especially barriers related to finance costs.

Renewable energy procurement auctions have distinguished themselves as a very effective policy instruments capable of significantly incentivizing private investments into renewable energy sectors worldwide, while at the same time minimizing support costs by competitively driving down the price of electricity generated from renewables. These features, as well as the adaptability of auctions to cater also to secondary policy objectives and priorities, render them highly attractive also to policy makers in developing countries.

This thesis has shown that auctions are capable of driving renewable energy deployment while minimizing support costs also in developing countries, but more importantly, that auctions on their own are not a panacea on which policymakers can rely solely. More importantly, and especially with respect to indirect, underlying, and structural issues such as human capacity deficits, a broad but aligned policy mix is required to ensure the effective functioning of each policy component in isolation.

The four papers published as part of this thesis have contributed to the understanding of the unique challenges faced by developing countries in promoting greater renewable energy penetration, as well as have evaluated the viability of deploying renewable energy procurement auctions to this end.

Lucas *et al.* (2017) have confirmed findings of previous studies highlighting economic and regulatory barriers as especially prevalent in developing country context, based on the case study of Pacific SIDS, but have further stressed the need to consider capacity building needs. This concern has been picked up by Lucas, Pinnington and Cabeza (2018), where it is argued that capacity skill gaps are found to be the result of inadequately designed renewable energy education and training programmes and a general mismatch of education sector offer and industry demand. This analysis reflects a structural issue that was found to be putting energy transition progress on risk globally, but also and especially in developing countries where further research is required on how to improve, increase and facilitate training to professionals in developing countries, adapted to their educational system conditions, renewable energy market conditions. In addition, there is a need to research on ways to adapt the educational offer to the rapid changing conditions of the renewable energy markets. Last but not least, there are evidences on the prominent role that women should play in the renewable energy transition, while their enrolment in science, technology, engineering and mathematics studies still rather low, further research is needed on fostering qualified women for the renewable energy sector.

In the second leg of the analysis, the viability of auctions for applications in developing countries and to address persisting deployment barriers were evaluated. Lucas, del Rio and Sokona (2017) found renewable energy auctions in Sub-Saharan Africa to be delivering well on their promise of procuring renewable energy capacity at efficient prices, also due to the adaptability of auctions to address specific barriers via the choice of appropriate design elements. However, the study has also highlighted that the success of auctions in developing countries critically depends on established enabling conditions and frameworks, comprising among other factors sufficient human capacity. Auctions in other parts of the world, such as Turkey's YEKA auction scheme (Sarı, Saygın and Lucas, 2019), provide examples of approaches to ensuring capacity building and research and development promotion along the implementation of successful projects. However, bloating up auction schemes to cater to multiple secondary objectives renders processes increasingly complex and difficult for especially small actors to comply with, as well as obviously also resulting in higher electricity prices.

Finally, taking into consideration that many developing countries are still facing significant electricity access gaps, and that just and inclusive energy transitions should not leave anyone behind, the analysis is completed by an evaluation of the applicability of renewable energy auctions for the procurement of energy services (as opposed to capacity or generation) in the context of rural electrification in Peru. Once again, the adaptability of auctions via the diligent choice of adequate design elements was confirmed and allowed for competitively procuring the establishment of electricity connections for households through stand-alone solar PV systems at low prices. The applicability of auctions, however, to nascent or niche market contexts characterized by low competition, is problematic and may lead to non-efficient outcomes.

Further research is required on case studies on the design elements and implementation of renewable energy auctions in developing countries. In addition, the role of international financial institutions and cooperation agencies in renewable energy auction programmes in developing countries as well as the role of de-risking instruments to enhance the result of the auctions.

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