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The Transition Towards a Green Economy and its Implications for Quality Infrastructure

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102

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Contents

Boxes

Figures

Tables

Appendix Tables

Abbreviations

AADR	Addis Ababa-Djibouti Railway
AAGR	average annual growth rate
AAIT	Addis Ababa Institute of Technology
AALRT	Addis Ababa Light Rail Transit
ACMA	Automotive Components Manufacturers Association (India)
AETDPD	Alternative Energy Technology Development and Promotion Directorate (Ethiopia)
AFD	French Development Agency / Agence Française de Développement
AFRIMETS	Intra-Africa Metrology System / Système Intra-Africain de Métrologie
AMEE	Moroccan Agency for Energy Efficiency / Agence Marocaine pour l'Efficacité Energétique
ARAC	Arab Accreditation Cooperation
ARAI	Automotive Research Association of India
ATA	Agricultural Transformation Agency (ATA)
BEE	Bureau of Energy Efficiency (India)
BIS	Bureau of Indian Standards
BMZ	Federal Ministry for Economic Cooperation and Development (Germany) / Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung
BRT	bus rapid transit
CCECC	China Civil Engineering Construction Corporation
CEEW	Council on Energy, Environment and Water (India)
CENELEC	European Committee for Electrotechnical Standardization / Comitato europeo di normazione elettrotecnica
CEREP	Center for Studies and Research on the Environment and Pollution (Morocco) / Centre d'Etudes et de Recherches sur l'Environnement et la Pollution
CETEMCO	Center for Building Techniques and Materials (Morocco) / Centre des Techniques et Matériaux de Construction

CII	Confederation of Indian Industry
CGEM	General Confederation of Moroccan Enterprises / Confédération Générale des Entreprises du Maroc
COMAC	National Committee for Accreditation (Morocco) / Comité Marocain d'Accréditation
CPC	Cooperative Patent Classification
CPCB	Central Pollution Control Board (India)
CREC	China Railway Group Limited
CRGE	Climate Resilient Green Economy (Ethiopia)
CSE	Centre for Science and Environment (India)
CSIR	Council of Scientific and Industrial Research (India)
CSNCA	High Council for Standardization, Certification, Accreditation and Promotion of Quality (Morocco) / Conseil Supérieur de Normalisation, de Certification et d'Accréditation et de la Promotion de la Qualité
CTM	Lydec's Technical Centre for Metrology (Morocco) / Centre Technique de Métrologie de la Lydec
DCEM	Department for Water Quality Assurance (Morocco) / Direction du Controle de la Qualité des Eaux
DIE	German Development Institute / Deutsches Institut für Entwicklungspolitik
DPCSMQ	Department for Consumer Protection, Market and Quality Assessment (Morocco) / Direction de la Protection du Consommateur, de la Surveillance du Marché et de la Qualité
ECAE	Ethiopian Conformity Assessment Enterprise
ECBC	Energy Conservation Building Code (India)
ECBP	Engineering Capacity Building Program (Ethiopia)
EDS	Environmental Design Solutions (India)
EEP	Ethiopian Electric Power
EESL	Energy Efficiency Services Limited (India)
ENAO	Ethiopian National Accreditation Office
ENIM	Rabat School of Mines (Morocco) / École Nationale Supérieure des Mines de Rabat

EPC	engineering, procurement and construction
EPO	European Patent Office
ERA	Ethiopian Railway Academy
ERC	Ethiopian Railways Corporation
ESA	Ethiopian Standards Agency
EV	electric vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (India)
FAO	Food and Agriculture Organization
FDI	foreign direct investment
GDP	gross domestic product
GERD	Grand Ethiopian Renaissance Dam
GHG	greenhouse gas
GIZ	German Agency for International Cooperation / Deutsche Gesellschaft für Internationale Zusammenarbeit
GoE	Government of Ethiopia
GRIHA	Green Rating for Integrated Habitat Assessment (India)
GTP	Growth and Transformation Plan (Ethiopia)
GVCs	Global value chains
GW	gigawatt
HVAC	heating, ventilation and air conditioning
IAF	International Accreditation Forum
IAIP	integrated agro-industrial park
ICE	internal combustion engine
ICS	improved cookstove
ICT	information and communications technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IIT	Indian Institute of Technology
ILAC	International Laboratory Accreditation Cooperation

IMANOR	National Institute for Standards (Morocco) / Institut Marocain de Normalisation
INSS	Indian National Strategy for Standardization
IRESEN	Research Institute for Solar Energy and New Energy Technologies (Morocco) / Institut de Recherche en Énergie Solaire et Énergies Nouvelles
ISO	International Organization for Standardization
L2MI	Moroccan Laboratory for Industrial Metrology / Laboratoire Marocain de Métrologie Industrielle
LG	Lighting Global
LNM	National Metrology Laboratory (Morocco) / Laboratoire National de Métrologie
LNESP	National Laboratory for Pollution Assessment and Monitoring (Morocco) / Laboratoire National des Etudes et de Surveillance de la Pollution
LPEE	National Laboratory for Trials and Studies (Morocco) / Laboratoire Public d'Essais et d'Etudes
MAGMET	North African Metrology Network / Réseau Maghrébin de Métrologie
MASEN	Moroccan Agency for Sustainable Energy
MIICEN	Ministry of Industry, Trade and Green and Digital Economy (Morocco) / Ministère de l'Industrie, du Commerce et de l'Économie Verte e Numérique
MoEFCC	Ministry of Environment, Forest and Climate Change (India)
MoRTH	Ministry of Road Transport and Highways (India)
MoWIE	Ministry of Water, Irrigation and Energy (Ethiopia)
MW	megawatt
NABCB	National Accreditation Board for Certification Bodies (India)
NABL	National Accreditation Board for Testing and Calibration Laboratories (India)
NAPCC	National Action Plan on Climate Change (India)
NDC	nationally determined contribution
NEERI	National Environmental Engineering Research Institute (India)

NEMM	National Electric Mobility Mission (India)
NGO	non-governmental organisation
NILU	Norwegian Institute for Air Research
NMEEE	National Mission for Enhanced Energy Efficiency (India)
NMIE	National Metrology Institute of Ethiopia
NPL	National Physical Laboratory (India)
NQI	national quality infrastructure
OCP	Office Cérifien des Phosphates (Morocco)
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
ONEE	National Office of Drinking Water (Morocco) / Office National de l'Électricité et de l'Eau Potable
PAT	Perform, Achieve and Trade (India)
PM	particulate matter
PNDM	National Solid Waste Management Programme (Morocco) / Programme National des Déchets Ménagers
PROMASOL	Programme for the solar water heaters market development in Morocco / Programme de développement du marché marocain des chauffe-eau solaire
PTB	National Metrology Institute (Germany) / Physikalisch-Technische Bundesanstalt
PVoC	pre-export verification of conformity
PV	photovoltaic
QCI	Quality Council of India
QI	quality infrastructure
R&D	research and development
SDO	standards developing organisation
SECI	Solar Energy Corporation of India
SEMAC	National Office for Accreditation (Morocco) / Service Marocain d'Accréditation
SHS	solar home system

SPCB	State Pollution Control Board (India)
SWH	solar water heater
TERI	The Energy and Resources Institute (India)
UJALA	Unnat Jyoti by Affordable LEDs for All
UMAQ	Moroccan Union for Quality / Union Marocaine pour la Qualité
UN Environment	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
USPTO	United States Patent and Trademark Office
WHO	World Health Organization
WTO	World Trade Organization

Executive summary

The transition towards a green economy has become both a need and a reality in most parts of the world. This implies accelerated diffusion of manifold green technologies, which in turn opens up opportunities for domestic value creation in terms of learning, localisation of supply chains and employment. An important, but largely neglected, pre-condition for the effective development and diffusion of green technologies and gains in competitiveness is the presence of well-functioning national quality infrastructure (NQI) systems. Quality infrastructure (QI) comprises standards, conformity assessment (that is, inspection, testing and certification), metrology, accreditation and in specific areas, technical regulation. QI is necessary for securing access to new markets, improving competitiveness and productivity, enabling innovation and ensuring environmental and consumer protection. Building up relevant NQI capabilities early on in the transition to a green economy is, therefore, decisive for effectively using, adapting and innovating technologies.

This study contributes to closing an important dual research gap by exploring (a) which green technologies are diffusing at what pace in developing countries and (b) what QI investments are needed to support and benefit from this green transition. We distinguish between emerging economies and developing countries, exploring expected trends in the innovation and diffusion of green technologies within this decade (by 2030). We use a combination of methods and data sources (patent data analysis, Delphi surveys, in-depth interviews and qualitative needs assessment in three country case studies) to explore the following research questions:

- Which families of green technologies have seen faster rates of innovation in the past decades as measured by patent data? How has innovation in green technologies been “distributed” across countries?
- Which families of green technologies are likely to see faster rates of deployment in the next ten years in emerging and developing countries? How technologically demanding are these technologies and to what extent will we see trends towards domestic value creation and technological learning in developing and emerging countries? Given these trends, what can be done with respect to QI investments to support the deployment and use of green technologies in developing and emerging economies?

- What are the existing gaps in terms of QI capabilities in specific developing and emerging countries (India, Morocco and Ethiopia) and what policy interventions would be necessary to build up the needed QI to facilitate the transition to a green economy? What lessons can be derived for national policy makers and for national QI institutions and their international partners, such as Germany's National Metrology Institute (PTB), to enable the transition towards a green economy?

Our analysis shows that innovation in green technologies has increased significantly since 1975 and again since 2005. Competition in green technology development has also intensified, with some Asian countries (especially China and South Korea) catching up with the traditional leaders in green innovation. At a lower level, a dozen larger emerging economies are clearly stepping up green innovation efforts, whereas developing countries in general still lag behind significantly.

Yet, our findings suggest that this decade the transition to a green economy and the use of green technologies will accelerate in both emerging and developing countries. In particular, emerging economies are likely to see moderate to rapid market development in most green technologies (such as electricity generation, waste management, transportation and energy efficiency in buildings). China and India stand out regarding expectations for market development, while in other emerging economies the direction is less clear. Up to 70 per cent of value added and technological capabilities are expected to be provided locally (the number is lower for those green technologies with a high degree of sophistication, such as concentrated solar power, battery energy storage, and plug-in and fuel cell vehicles). Yet, for technologies with a high degree of sophistication, even in emerging economies little value added (less than 30 per cent) is expected. For such technologies (e.g., concentrated solar power (CSP), battery energy storage, and plug-in and fuel cell vehicles), most innovation will come from developed countries.

Developing countries are likely to see rapid market development only in selected technologies (solar photovoltaic (PV) energy, recycling and drought resistant crops, for example). Market development for most other green technologies will only be moderate between now and 2030. Reasons behind this slower growth relate to, among other things, less ambitious and consistent policies, lower financing and investment, and weaker implementation and maintenance capabilities. Domestic value added and technological capabilities will remain low (less than 30 per cent) for most green technologies, except for technologies that are currently more mature, such as solar PV or micro-hydropower systems, where services and some manufacturing can be localised.

These trends in market development and domestic technological capabilities have distinct implications for the needed QI investments. We also find important differences between the needed QI interventions depending on whether a country mostly imports green technologies or produces most parts and components locally. Our findings also show that most green technologies with a medium to high degree of sophistication (or related technologies) also require a highly sophisticated QI system. Thus, where markets are expected to grow faster for such technologies, QI capabilities also need to be upscaled and upgraded. Examples of such technologies are energy storage in batteries, solar PV technologies, recycling of e-waste and building materials and a range of technologies related to energy efficiency in buildings. Yet, the level of needed QI-related interventions varies across developed and emerging economies. As emerging economies have higher technological capabilities and more established NQI systems compared with developing countries, international cooperation in the QI space should focus especially on improving the effectiveness of existing QI services and institutions. In developing countries, international cooperation should aim at building up the necessary NQI system. Green technologies associated with, for instance, energy generation (e.g., solar and wind, hydropower and storage), energy efficiency technologies (e.g., heating, ventilation and air conditioning (HVAC), lighting and solar cooling), transportation (e.g., bus rapid transit (BRT) and inter-modal transportation) and waste management would require support to build up the necessary QI capabilities to enable market development. At the aggregate level (across countries), but for a select group of green technologies (e.g., wind energy, CSP, battery energy storage, solid waste management, energy efficiency in buildings and agriculture), we also examined which QI elements are in need of improvement. We found that those green technologies require interventions in all QI system components but to different degrees depending on the sophistication and maturity level of the technology.

To understand at a more granular level the transition to a green economy, we examine in great detail the opportunities and challenges associated with this process and the QI interventions that are needed to accelerate the transition in three case studies: India, Morocco and Ethiopia. We observe differences across countries in the effectiveness of the NQI system and discuss how national policy makers and international development cooperation actors can support the efficiency and effectiveness of the NQI system. We also identify different patterns in greening the economy (in terms of the choice of technologies and pace of transition) depending on domestic needs and resources. Despite these differences, we also identify some commonalities across the case studies related to QI capabilities and the transition to a green economy:

- *QI services should be closely aligned with technology-level strategies.* When this has been the case (e.g., energy efficiency in buildings in India), diffusion of green technologies has occurred more quickly. A failure to do so (e.g., solid waste management in Ethiopia) is likely to slow down significantly the transition to more sustainable practices. This also emphasises the necessity to conduct QI needs assessments for specific sectors. With a few exceptions (energy efficiency in India, metrology needs for solar PV in Morocco) such needs assessment efforts were not conducted, which has implications not only for the speed of transition but also for the coordination across stakeholders, and the effectiveness of interventions.
- *System integration and the respective QI capabilities are highly needed and relevant for several green technologies.* This is the case for technologies such as sustainable transportation (grid stability as a result of e-mobility, renewable energy for charging stations), electricity generation (smart grids to balance and manage different sources of energy) and desalination (increasingly relying on solar and wind power), for example. Knowledge on the necessary QI is still limited in this area and domestic capabilities (also in terms of identifying needs) is especially low.
- *Awareness of QI and its various benefits for the economy, environment and society remain limited and should be expanded.* Green economy issues are relatively new for consumers, the private sector and QI staff. Hence,

awareness of the green transition and quality issues is needed everywhere, as is training on these new technologies. Low awareness reduces the demand for QI even when the environmental problems are acute (e.g., Morocco and Ethiopia). The more the private sector is sensitised to the relevance of QI, the more it will demand standards and conformity assessment services, for instance. Considering that the transition towards a greener economy has a public goods character, it might be necessary to use subsidies to reduce the cost burden of conformity assessment, thereby, lowering the barriers for private companies.

- *Implementation capabilities need to be strengthened (but to different degrees) in all these cases.* Several factors contribute to low implementation capabilities including a lack of technical knowledge on specific technologies (in all cases as we will see below); a lack of staff (e.g., India); a lack of compliance; weak surveillance; corruption (e.g., Morocco and Ethiopia); and unclear sub-national governance structure (e.g., India). Understanding why implementation capabilities are weak in a particular country and sector is important for designing effective interventions.

Based on the combined assessments (patent analysis, foresight assessment based on Delphi surveys and in-depth country case studies), we draw a range of conclusions for national policy makers and development cooperation stakeholders in the area of QI. Specifically, as a range of green technologies are now rapidly diffusing in developing and emerging countries and most required QI services are not in place, NQI institutions need to invest more in technology foresight and market observation to anticipate needs. If NQI systems are not adapted quickly, countries risk investing in inappropriate technologies, which will lead to project failure and underperformance. Moreover, as NQI needs vary across techno-industrial ambitions, development cooperation should systematically distinguish QI offers considering strategic opportunities and constraints at the country level. However, policy makers should assess political interests and related risks when helping to set up national laboratories and establishing NQI systems. QI national stakeholders may wish to have a range of sophisticated facilities and a mandate to run a wide range of conformity assessment services, even when there is little demand for such services. Further, we have also found that NQI systems are often not well integrated, for example, there is little cooperation across the "pillars" of the system, reducing their effectiveness. System integration should, therefore, be emphasised (even of not all elements of an NQI system are present locally). This would ensure a "smart" system in which national capacities are allocated as needed and complemented when necessary with international systems.

1 Introduction

Technology and policy developments of the past decade indicate that the world may be moving towards more environmentally sustainable growth pathways. The 2015 signing of the Paris Agreement in which governments made binding commitments to present national decarbonisation strategies testifies to this global interest in more sustainable growth models (Fankhauser & Stern, 2016). Such low-carbon transitions would necessarily result in a profound transformation of production structures in both developed and developing countries, as the economic changes required to combat climate change are not marginal but systemic (Perez, 2009). Given that humankind is transgressing various planetary boundaries (Rockström et al., 2009; Steffen et al., 2015), there is an urgent need to redesign economic incentives to ensure that, for instance, fewer resources are consumed, used products are repaired or recycled, and soil fertility and biodiversity are preserved (Altenburg & Rodrik, 2017).

Empirical evidence confirms that on average, green technologies develop faster (as measured by patent data) than other technologies. While the average global rate of patent filing grew by 6 per cent between 2006 and 2011, the combined rate of growth for key renewable energy technologies (solar photovoltaics (PV), solar thermal, wind energy, and biofuels), for example, has been 24 per cent over the same period (Helm, Tannock, & Iliev, 2014). Consequently, some green technologies are already technologically mature and increasingly crowding out polluting incumbent industries on the basis of price competitiveness. This is the case for various renewable energy technologies (REN21, 2018), and many others, such as electric vehicles (EVs) for which battery price reductions are expected to bring the total cost of ownership below that of conventional vehicles within the next 15 years, even with low oil prices (BloombergNEF, 25 February 2016). In parallel, environmental regulations are becoming stricter, thereby creating demand for technologies that lessen pollution and energy-efficient alternatives. We also find a diversification of players in green patenting and a shift towards East Asia, with China and South Korea being particularly dynamic in green innovation.

As markets for green technologies increase and become more interconnected, the requirements for quality infrastructure (QI) also change. QI comprises standards, conformity assessment, metrology and accreditation. New standards are needed as new products are developed locally or imported.

Environmental performance needs to be improved (e.g., by reducing pesticide residues in food) as consumer demand increasingly shifts towards products and processes that do not harm the environment. Increasing awareness of the health risks related to water and air pollution pushes governments to strengthen laws and regulations related to environmental monitoring. Technical standards must ensure that product testing is done with appropriate techniques and equipment. Testing labs have to be accredited to ensure international acceptance of results. Metrology must ensure that the measurement technologies are up-to-date, and that equipment is calibrated at reasonable time intervals. Technical regulation against technical standards and for public health and security, or for environmental reasons, can be seen as a fifth element of the QI system. Overall, an effective QI is important to make the "green transformation" happen and to accelerate its implementation.

For QI stakeholders such as Germany's National Metrology Institute (PTB) and its international partner institutions it is thus important to closely monitor such new demands and opportunities and develop the respective services in emerging green technology markets. Early development of QI services linked to green technologies helps to, for instance, (a) implement environmental protection more effectively in critical areas, such as air pollution and climate change mitigation (e.g., air pollution control technologies); (b) reduce investment risks in emerging green technologies (e.g., performance over time of wind turbines and solar panels); and (c) contribute to developing competitive advantage. While for most developing country governments the main objective is to accelerate the adoption and deployment of green technologies and business models, some also have ambitions to produce green technologies at scale, export them and encourage technology spillovers into other parts of their economies. For those countries, building up relevant QI capabilities early on is decisive for ensuring competitiveness and facilitating entry in foreign markets.

So far, studies on the diffusion of green technologies have focussed primarily on OECD countries (see, e.g., Dechezlepretre, Glachant, & Meniere, 2010; Fankhauser et al., 2013) and a few emerging economies, particularly China (Altenburg, 2015; Fankhauser & Kotsch, 2018). This reflects two difficulties in exploring developing country trends. Firstly, the development and deployment of green technologies is a relatively new phenomenon globally, and it is still at an embryonic stage in most developing countries (with some notable exceptions, such as solar water heaters, solar PV and wind turbines). Secondly, there is hardly any specialised, systematic data collection on impacts of and needs from green technology deployment in developing countries. Additionally, while in terms of needed capabilities, emphasis tends to be placed on (general and technology-specific) education and training, research and development (R&D) investments and policy driven incentives, less attention has been given to QI despite the role it plays in using, adapting and innovating technologies.

To fill this gap, this study explores trends in green technology innovation and the diffusion of these technologies in developing and emerging economies.[1] It identifies general gaps in QI capabilities in these countries and zooms into the micro-level in three country studies. A combination of methods and data sources (patent data analysis, Delphi surveys, in-depth expert interviews and qualitative needs assessment) is used to explore the following research questions.

- Which families of green technologies have seen faster rates of innovation in the past decades, as measured by patent data? How has innovation in green technologies been "distributed" across countries? (see Chapter 3)
- Which families of green technologies are likely to see faster rates of deployment in the coming decade in emerging and developing countries? How technologically demanding are these technologies and to what extent do we see trends towards domestic value creation and technological learning in emerging and developing countries? (see Chapter 4)
- Given these trends, what are the expected needs with respect to QI investments to support deployment and use of green technologies in developing and emerging economies? (see Chapter 4)
- What are the existing gaps in terms of QI capabilities in specific developing and emerging countries (India, Morocco and Ethiopia) and what policy interventions would be necessary to build up the needed QI to facilitate the transition to a green economy? (see Chapter 5)
- What lessons can be derived for national policy makers, national QI institutions and PTB to enable the transition towards a green economy? (see Chapter 6)

Before we explore these questions in greater detail, Chapter 2 briefly discusses the less researched system of QI and its importance for improving

1 This research was conducted in close collaboration with, and funded by, Germany's National Metrology Institute (PTB).

competitiveness and technology development with a focus on the green economy. In this chapter, we also introduce the families of green technologies that are explored in more depth in this study.

2 Quality infrastructure and the green economy

QI, as an element of the institutional meso-level of a competitive economy, has been under-researched in the economic development and innovation systems literature. Getting a basic understanding of the elements of the QI system, how they are interrelated, and what role they play in the transition to a green economy is critical before we explore our main research questions in the following chapters. We start by introducing the key elements of the QI system and then we briefly explain the role of the QI system in the transition to a green economy.

2.1 Quality infrastructure: a system of interrelated services

Kellermann (2019) defines the QI system "as comprising the organizations (public and private), policies, and relevant legal and regulatory frameworks and practices needed to support and enhance the quality, safety, and environmental soundness of goods, services, and processes" (p. 4). A well-functioning QI system is essential for improving competitiveness and productivity, for enabling entry in new markets, for fostering innovation in new products and processes, and for promoting environmental performance, health and safety. The four core elements of an effective national quality infrastructure (NQI) are as follows (Kellermann, 2019; see Table 1).

- *Standardisation* is the use of a system of standards. The International Electrotechnical Commission (IEC) define a standard as a "document, established by consensus and approved by a recognised body that provides, for common and repeated use, rules, guidelines, or characteristics for activities or their results" (IEC, n.d.).
- *Conformity assessment* is a bundle of services that demonstrates that specified requirements of a product, process, system, person or body are fulfilled. These requirements are stated in regulations, standards and technical specifications.
- *Metrology* is the science of measurement and its applications. Within the QI context, it ensures the optimal level of measurement accuracy

and clearly defined uncertainties. Metrology can be separated into three categories: scientific, legal and industrial metrology.

- *Accreditation* in the QI context is the formal attestation or statement by an independent third party, that a conformity assessment body or calibration laboratory is capable of carrying out a specific task or service.

The QI organisations providing these services are interdependent and part of complex national and international network, hence the distinction between QI systems and NQI systems.[2] Aside from the above main QI pillars, technical regulations are "a mandatory part of the QI – being legally binding prescriptions – whereas standards compliance is voluntary" (Kellermann, 2019, p. 12). Governments implement them mainly for security, health and environmental reasons and to prevent deceptive practices. They may, however, also be abused as non-tariff barriers to trade.

In industrialised countries, NQI systems have emerged over decades in an interplay of increasing diversification and internationalisation of the business sector and institutional sophistication in private and public QI service provision. Standards develop over time, as new requirements for norms arise, to be able to respond to the increasing complexity of shifts within the economy. Conformity assessment is not only done by public entities, but also by private service providers accredited by a national accreditation body. In developing countries, NQIs have a shorter history. In many countries, specialised institutions for the key functions of NQI have not yet developed, and different functions are therefore provided by one governmental body. NQI systems in developing countries often encounter challenges on the supply and demand sides simultaneously. On the supply side, QI bodies typically lack adequate facilities (such as metrology and testing labs) and experience shortages of qualified staff (Harmes-Liedtke, 2010). Likewise, there is little demand for QI services when countries are not yet fully industrialised, mostly trade unsophisticated goods and domestic consumers do not demand certified quality. Supply and demand constraints may easily reinforce each other, thereby locking countries into a vicious cycle of underperformance. Striving to develop the NQI system may then become one of the most important enablers of catch-up development.

2 Throughout this report the term "QI" refers to the system of four (or five, if technical regulation is included) functional elements and their interaction. "NQI" refers to a concrete QI system within a national economy as influenced by national policy making.

Table 1: NQI services and associated institutions

Service		**Description**	**Institutions involved**
Standards		Publication of a formal document (standard), generally developed by consensus, containing the requirements that a product, process or service should comply with. Standards are essentially voluntary, and producers can choose whether to use them. Once standards are contained in contracts or referenced in technical regulations compliance with them becomes a legal or de facto obligation.	National standards body Sectoral standards development technical committees Industry standards organisations
Conformity assessment	**Inspection**	Examines a design, product, process or installation and determines its conformity with specific requirements or, based on professional judgement, with general requirements.	Import inspection agencies General inspection agencies
	Testing	Determines a product's characteristics against the requirements of a standard.	Testing laboratories (analytical, materials, medical testing labs, etc.) Pathology laboratories Environmental laboratories
	Certification	Formal substantiation by a certification body after evaluation, testing, inspection or assessment that a product, service, organisation or individual complies with the standard.	Product certification organisations System certification organisations

Table 1 (cont.): NQI services and associated institutions		
Metrology	Comprises three fields: *Scientific metrology*: development and organisation of the highest level of measurement standards. *Legal metrology*: ensured correctness of measurements with relevance to trade, law enforcement, health and safety. *Industrial metrology*: satisfactory functioning of measurement instruments used in industry, production and testing by the national metrology institute.	National metrology institutes Calibration laboratories Legal metrology entities
Accreditation	Provides independent attestation of the competency of an organisation/ individual to offer specified conformity assessment service.	National accreditation body (NAB)
Source: Based on Kellerman (2019)		

2.2 The importance of NQI systems in the transition towards green economies

The present study refers to QI needs in the transition to a green economy. The United Nations Environment Program (UN Environment) defines the green economy as an economy that is "low carbon, resource efficient, and socially inclusive" (UNEP, 2011, p. 6). Further, UN Environment refers to green (or environmentally sound) technologies as

> technologies that protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable way than the technologies for which they are substitutes. (UNEP, n.d., p. 1)

This implies two important aspects that make research into green technologies challenging. First, green technologies play a role in all economic activity for a wide variety of purposes, such as electricity generation, water management, emissions reduction, energy efficiency, transport, manufacturing and agriculture. Second, green and non-green technologies are often applied in combination rather than in isolation. While solar and wind energy generation is clearly green and fossil fuel energy generation is non-green, many industries combine green and non-green products and processes, and the shift to greener economies mostly results from incremental improvements.

For the purpose of this study, however, we need an operational definition of "green technologies". For patent analysis, we draw on the list of climate change mitigation technologies that the European Patent Office (EPO) co-developed with the UN Environment and the International Centre on Trade and Sustainable Development (ICTSD). For our survey and country studies we assembled a similar list based on green technology classifications provided by the United Nations Framework Convention on Climate Change (UNFCCC) and the ClimateTechWiki (n.d.).[3] Here, we grouped green technologies into eight main groups or sectors, which we subsequently use in our empirical analyses (see Table 2). Each sector lists the most common and available technologies at a rather aggregate level for simplicity's sake. Each listed technology can be broken down into technology "types" with different maturity and sophistication (or parts and components with various degrees of sophistication when it comes to design and manufacturing); these have different implications for patterns of market development and the difficulty of building domestic capabilities. In our more detailed analyses, we differentiate where possible (see Chapter 4).

Table 2: Categorisation of green technologies used in this study

Technology sector	Selected technologies
Electricity	Wind energy
	Concentrated solar power
	Solar PV
	Solar water heaters
	Ocean energy
	Hydropower
	Geothermal
	Battery energy storage
	Thermal energy storage
	Co-generation
	Smart power grids
	Bioenergy

3 The ClimateTechWiki is an open platform that offers detailed information on a broad set of mitigation and adaptation technologies, case studies, best practice examples and publications.

Table 2 (cont.):	**Categorisation of green technologies used in this study**
Water management	Desalinisation
	Wastewater treatment
	Water metering
	Rainwater harvesting
	Grey water reuse systems
Waste management	Recycling of paper, glass, aluminium
	Recycling of electronic and electrical equipment waste
	Recycling of building materials (e.g., urban mining)
	Composting
	Anaerobic digestion
	Gasification or combustion of municipal solid waste
	Methane capture at landfills for electricity and heat
Transport	Bus rapid transit (BRT)
	Inter-modal transportation systems
	Energy efficiency in transportation
	Electric and plug-in vehicle technology
	Hydrogen fuel cell vehicles
	Advanced bio-hydrocarbon fuels
Energy efficiency in buildings	Building energy management systems
	Smart meters
	Thermal insulation
	Energy efficient lighting
	Heating, ventilation and air conditioning (HVAC) systems
	Solar cooling and hybrid systems with heating and hot water
Cooking	Household biogas digesters
	Solar cookers
	Ethanol cookstoves
Agriculture and soil	GM crops
	Genome editing (CRISPR/Cas)
	Organic agriculture
	Urban agriculture
	Higher yield seeds (for arid and saline soils)
	Drought resistant crops and cultivation practices
	Solar water pumps
	Soil and water remediation
Other environmental technologies	Carbon capture and storage
	Environmental analytics and monitoring tools
	Carbon footprinting tools
	Energy efficiency in industrial processes
Source: Based on the technology lists provided by the ClimateTechWiki (n.d.)	

QI has an important role to play specifically in the context of the green transformation. When a new, green technology is introduced to a country, adoption of international standards can make sure that technical information is rapidly available.[4] When national standards organisations adopt international standards (for instance, ISO, IEC or the International Plant Protection Convention (IPPC)), this can be seen as a mode of knowledge and technology transfer, as knowledge about (green) technologies is transferred from the international to the domestic level. As international standards are developed by consensus by technical committees that bring together different stakeholder groups, the knowledge that can be transferred via standards is highly relevant. In addition, standards are regularly revised and thus represent the state of the art. Knowledge transfer is also realised through the participation of national experts in international technical committees. Some advanced and large developing countries participate in several hundred technical committees, for example, India participates in 664, South Africa (434), Argentina (383), Peru (60), Costa Rica (45) and Nigeria (74) (Harmes-Liedtke & Oteiza di Matteo, 2019), while others do not participate at all. Considering that most countries in the Global South lag behind the industrialised world in terms of mainstreaming sustainability issues in society and the business sector, the international links in standardisation can be an important lever for the global spread of sustainability-related thoughts, for example, because of relevant discussions in international technical committees.[5] Standards are also used as guiding principles for government procurement, which is increasingly seen as a lever for the sustainability transition, conceptualised as either “green public procurement” (GPP) or “sustainable public procurement” (SPP). Many of those standards are so-called voluntary sustainability, which are outside the range of NQI systems in most countries (Kellermann, 2019). Environmental management

4 One main reason why diffusion of some technologies is lagging is the lack of quality standards for green products and technologies (infoDev, 2017). A variety of green products distributed in developing countries are low cost and low quality, which undermines emerging products that may be either better suited to the local environmental conditions or of higher quality and therefore higher prices (see Friedlander, Tal and Lazarovitch (2013) for drip-irrigation in Africa and Orlandi, Tyabji and Chase (2016) for solar water systems and other off-grid solar solutions). Initiatives that specifically target quality standards for off-grid solutions are the Lighting Global Quality Assurance Framework, the mini-grid assurance framework, and the Global LEAD Off-Grid Appliance Data Program.

5 The fact that developing countries are not adequately represented in international standard setting organisations has been recognised. Efforts are being made to improve the situation (ISO, 2016).

standards, such as ISO 14000, are, however, embedded in NQI systems, meaning that the national standards bodies align national standards to the ISO standards and conformity assessment bodies to ensure compliance.

In a flourishing economy, conformity assessment services will emerge in response to increasing demand from the business sector. The transition towards sustainable production patterns is loaded with market failures as long as environmental externalities are not fully reflected in production costs. In this situation, the state has to act and lower the entry barriers to the "green economy" in order to accelerate the transition. Based on a clear needs assessment and priority setting, public funds and donor financing should be used to broaden and deepen the supply of conformity assessment services in critical sectors. Yet, public investment in QI-related equipment, training of professional staff and provision of reference materials may be costly. For this reason, it is important to ensure that such conformity assessment services can be used at sufficiently high potential, that is, that national demand is sufficiently large. In addition to investment in hard- and software, the proficient usage of equipment must be factored in. For instance, some countries, such as Kenya and Uganda, are working with pre-export verification of conformity to standards (PVoC) for regulated products, where accredited third parties in the producer countries check the conformity of deliverables with international and national standards. When the number of items to be tested and certified nationally is limited, conformity assessment services might be bought from international providers. Thus, as the domestic market for the green technologies grows, so does the need for a range of nationally based conformity assessment services.

Effective conformity assessment depends on good technical measurement capabilities, that is, metrology. In the process of a green transition, new parameters and higher levels of accuracy may be required. Examples are local and regional contamination of air and water bodies and greenhouse gas (GHG) emissions from industry, which are, for instance, reported in the context of nationally determined contributions. Equipment, such as wind turbines, require regular measurements of various parameters, in order to guarantee the best possible wind harvesting and to extend product lifetime. Measurement devices have to be calibrated on a regular basis, which is an additional important contribution of QI (specifically metrology) to an accelerated green transition.

Accreditation is “the formal attestation or statement by an independent third party that a [conformity assessment body] or calibration laboratory is competent” (Kellermann, 2019; 93) to carry out its activities, and is essential for QI services to be recognised internationally. In the context of the transition to a green economy (but not only), a dysfunctional accreditation process can either significantly hold back the deployment of green technologies or prevent the development of an effective NQI system.

Technical regulation, such as for environmental protection, frequently makes reference to standards as an internationally agreed good practice. For instance, a 2014 regulation to ban products of low energy efficiency from the public market in Costa Rica, makes a direct link to technical standards and related conformity assessment (Stamm et al., 2019). The World Trade Organization’s (WTO) Technical Barriers to Trade (TBT) Agreement proposes that all market interference by national governments be based on internationally agreed standards (also for green products), in order to avoid non-tariff trade barriers and ensure non-discriminatory market access. This aspect is relevant for the green transformation, as developing countries often argue that developed countries use protectionist measures in this sector by demanding higher and higher environmental performance of imported goods. Linking regulations with ISO or IEC standards reduces the risks of arbitrariness and covert protectionism.

3 Past trends in green technology development: a patent data perspective[6]

Before we explore future trends in the diffusion of green technologies in developing and emerging economies (and their implications for QI systems), we start with an incursion into the past and present to understand development trends across green technology types and across geographies. To do that we rely on patent data, which allows us to (1) identify which green technologies have seen fast rates of innovation in the past decades and are therefore more mature and thus likely to be diffused (at lower costs) in developing countries; (2) distinguish green technologies currently undergoing rapid innovation and thus playing an important role in greening economies only in the medium term, even if innovation may be concentrated only in a few

6 This chapter has been prepared by Nicoletta Corrocher and Andrea Morrison at Bocconi University, Italy.

developed countries; and (3) get an understanding of the geography of green innovation and trends in technology development across developed, emerging and developing countries.

We start with a short discussion on using patents for analysing trends in green innovation (Section 3.1), followed by a detailed analysis of green patenting activity by technology domain between 1975 and 2017 (Section 3.2). This investigation allows us to identify green technologies that have seen fast rates of development in the past, and thus are expected to diffuse more rapidly in developing and emerging countries. It also allows us to recognise green technologies that may be increasingly important for greening the economies of developing countries in the future. In Section 3.3 we examine the geography of green innovation, assessing which countries have played a large role in green innovation in the past and whether new players are emerging. We also delve deeper into the context of emerging economies to explore the technological focus of green innovation in specific countries. Section 3.4 summarises our main findings.

3.1 Using patents to assess trends in green innovation

Our assessment focuses on the evolution of climate change mitigation technologies, that is, technologies that aim to reduce the magnitude or rate of long-term climate change (e.g., renewables, waste treatment and technologies related to transportation and buildings), using patent data from the Patstat database. This database includes patents registered at all the existing national patent offices. In parallel to our analysis, we compare the overall Patstat data with the subset of patent filings in the United States Patent and Trademark Office (USPTO). As the market in the Unites States is highly competitive, patent filings indicate that an innovation meets a high standard and is of economic value. So, the comparison can be used as a proxy for quality in patent filing.[7]

In order to select the climate change mitigation technologies, we exploit the information from the classification system of patents. Each patent is

7 The Organisation for Economic Co-operation and Development (OECD) recommends using triadic patents, i.e., patents that have been applied for at the EPO, USPTO and Japan Patent Office (JPO), to control for quality. However, this condition would have been too restrictive in this case, as many developing countries do not patent extensively at the international level. Therefore, we have chosen to use a less restrictive condition to control for quality.

assigned one or more classification terms indicating the subject to which the invention relates; some patents are assigned additional classification terms that provide further details of its contents. Each classification term consists of a symbol, such as "Y02T10/7" for "Energy storage for electromobility". The first letter is the "section symbol", for example, "Y" for emerging cross-sectional technologies. This is followed by a two-digit number to give a "class symbol" (for instance, "Y02" represents "technologies or applications for mitigation or adaptation against climate change"). The final letter makes up the "subclass" (for instance, Y02T represents "climate change mitigation technologies related to transportation"). The subclass is then followed by a 1- to 3-digit "group" number, an oblique stroke and a number of at least two digits representing a "main group" or "subgroup" (such as, "/70"). A patent examiner assigns a classification to the patent application or other document at the most detailed level, which is applicable to its contents.

The current patent classification system is called the Cooperative Patent Classification (CPC); it is an extension of the International Patent Classification (IPC) and it is jointly managed by the EPO and the USPTO. It is divided into nine sections, A-H and Y, which in turn are sub-divided into classes, sub-classes, groups and sub-groups. The selected green technologies fall under the Y section, which includes nine classes (see Table 3).

We have extracted patent data in the Y02 and Y04S classes over the period 1975-2017[8]. The Y02 class covers selected technologies that control, reduce or prevent anthropogenic emissions of GHGs (in the framework of the Kyoto Protocol and the Paris Agreement) and technologies that allow adaptation to the adverse effects of climate change. The Y04S class covers systems that integrate technologies related to power network operation and communication and information technologies that improve electrical power generation, transmission, distribution, management and usage. Table 3 identifies the aggregated technological classes under investigation.

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8 Data was extracted from the most recent version of the Patstat database (2019). In principle there is always a delay of 18 months between the filing date and the publication date. Therefore, the most recent patent applications available in Patstat 2019 were filed in 2017.

Table 3: Green technology classes	
CPC Code	Name of the class
Y02A	Technologies for adaptation to climate change
Y02B	Climate change mitigation technologies related to buildings, e.g., housing, house appliances and related end user applications
Y02C	Capture, storage, sequestration and disposal of GHGs
Y02D	Climate change mitigation technologies in information and communications technology (ICT), i.e., ICT aiming to reduce its own energy use
Y02E	Reduction of GHG emissions related to energy generation, transmission and distribution
Y02P	Climate change mitigation technologies in the production and processing of goods
Y02T	Climate change mitigation technologies related to transportation
Y02W	Climate change mitigation technologies related to wastewater treatment and waste management
Y04S	Systems that integrate technologies related to power network operation and ICT that improves electrical power generation, transmission, distribution, management and usage
Source: Authors	

Each of the classes described above are composed of sub-classes. For the present analysis 57 classes and sub-classes are considered (see Table A1 in the Appendix). These classes were selected such that they are aligned with the categorisation of green technologies listed in Table 2 (representing some of the most relevant green technology families for developing countries), a list that we use later in the assessment of future trends and implications for QI (see Chapters 4 and 5). It is important to note, however, that in the patent analysis we also include other technology classes that have seen fast growth in innovation (as measured by the number of patents), specifically class Y02D and Y04S. These groups of technologies are expected to continue to see fast rates of development in the coming years. As many emerging and developing countries (including India and Morocco) are advancing their national digitalisation strategies, the use of these technologies (for instance in the energy sector in the form of smart grids) is expected to increase in the medium and long-term.

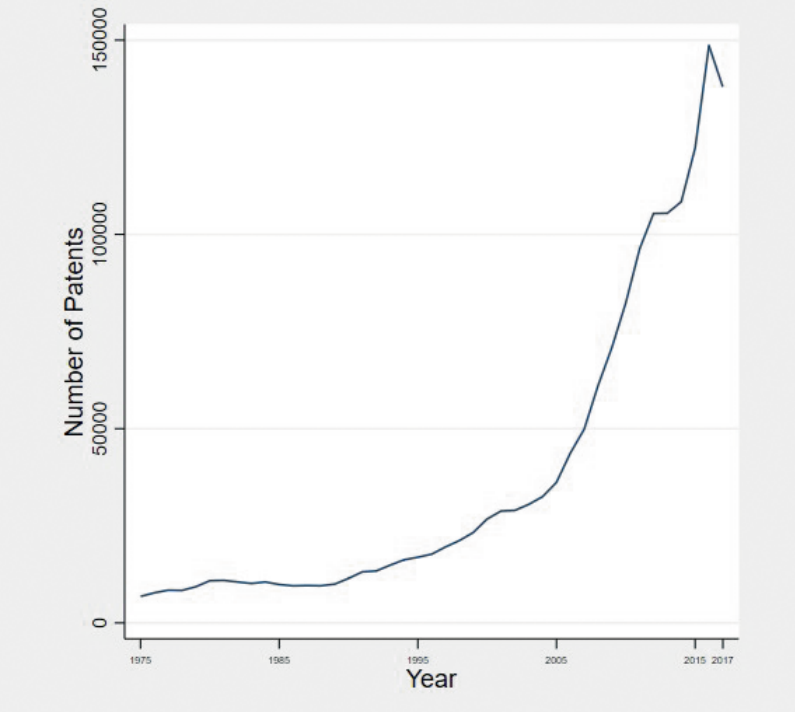
An important methodological issue concerns the fact that patent applicants can file their application at either one or more than one patent office. Applying at one office suggests that the innovation is not thought to be used elsewhere; conversely, patents filed in multiple jurisdictions can be considered globally valuable patents. If a certain patent is filed both at the EPO and at the USPTO, it appears in Patstat with two different application numbers, despite covering the same invention. To avoid double counting of essentially identical patents, we base our subsequent analysis on patent *families* that lump essentially identical filings in different jurisdictions together. In the rest of the report, we will refer to "patent families" as "patents".

3.2 Green patenting activity by technological domain

The database includes a total of 1,625,929 patents between 1975 and 2017. Figure 1 illustrates the number of patents per year and shows that innovations in the selected 57 climate change mitigation technological classes increased substantially over the period 1975-2017.[9]

9 The decline towards the end is partially related to the time it takes to record all the patent applications in Patstat. For this reason, the trend in earlier years suggests that patent activity will still show an upward trend between 2016 and 2017 once all patents are registered (i.e., once we have more up-to-date information). However, recent evidence from the OECD shows that there is a downward trend at least in high-quality green patent families (i.e., families with at least two patents).

Figure 1: Number of green patents by year, 1975-2017, all countries



Source: Authors

Table 4 shows the number of patents by aggregate technological class (4-digit) across the years. While we see a continuous increase in patenting activity, we also observe a boost in innovation in green technologies after 2005. If we look at the classes with the most patents, energy-related technologies (Y02E), transport-related technologies (Y02T) and technologies used in the production and processing of goods (Y02P) dominate, with a percentage over total patents of 35.2 per cent, 27.9 per cent and 25.6 per cent, respectively. Technologies related to adaptation to climate change (Y02A), buildings (Y02B) and waste management (Y02W) are also very well developed, while technologies related to ICT (Y02D), CO_2 capturing and storage (Y02C) and power operation networks (Y04S) lag behind in terms of the overall number of patents.

Table 4: Number of green patents by aggregate technological class*, all countries

Class code	Name	1975	1985	1995	2005	2015	Total	% of total patents
Y02A	Technologies for adaptation to climate change	1,987	2,432	4,753	7,455	30,341	367,337	18.3%
Y02B	Climate change mitigation technologies related to buildings, e.g., housing, house appliances and related end use applications	670	1,154	2,324	4,955	22,290	257,781	12.8%
Y02C	Capture, storage, sequestration and disposal of GHG	65	124	152	391	1,069	16,708	0.8%
Y02D	Climate change mitigation technologies in ICT, i.e., ICT aiming to reduce its own energy use	30	166	1,010	4,206	14,722	153,383	7.6%
Y02E	Reduction of GHG emissions, related to energy generation, transmission and distribution	3,769	6,504	6,211	13,877	46,685	706,272	35.2%
Y02P	Climate change mitigation technologies in the production and processing of goods	2,705	3,943	5,433	10,108	39,715	515,286	25.6%

Table 4 (cont.): Number of green patents by aggregate technological class*, all countries

Y02T	Climate change mitigation technologies related to transportation	1,862	2,795	6,099	14,108	37,464	560,724	27.9%
Y02W	Climate change mitigation technologies related to wastewater treatment and waste management	1,685	1,645	4,321	6,060	16,512	249,147	12.4%
Y04S	Systems that integrate technologies related to power network operation, ICT that improves electrical power generation, transmission, distribution, management and usage	63	128	289	659	6,173	56,747	2.8%

Note: *The total is higher than the total number of patents, since one patent can be assigned to more than one class. Therefore, "% of total patents" refers to the actual number of patents.
Source: Authors

Table 5 shows the top 10 technological classes at a more disaggregated level by number of patents across all countries over the selected time span. The most prolific class in terms of number of patents is energy storage for electromobility, which belongs to the aggregate class Y02T of climate change mitigation technologies related to transportation, with 10.5 per cent of total patents, followed by "adaptation technologies in agriculture, forestry, livestock or agroalimentary production"[10], with 10.2 per cent of total patents. The third class is solar PV, which belongs to the aggregate class Y02E of reduction of GHG emissions related to energy generation, transmission and distribution and accounts for 8.2 per cent of total patents. The fourth class – conventional vehicles/internal combustion engines (ICE)[11] – also belongs to the aggregate class Y02T of climate change mitigation technologies related to transportation and appears in 120,623 patents in total (7.4 per cent of total patents). The fifth class – techniques for reducing energy consumption in wireless communication networks – belongs to the aggregate class Y02D of climate change mitigation technologies in ICT and accounts for 6.7 per cent of total patents. Overall, if we consider the aggregate level, technologies related to transportation (Y02T) and technologies related to energy generation, transmission and distribution (Y02E) have the highest number of total patents.

10 Relevant technologies included in this class are pest and insect control; genetically modified organisms; plants resistant to insects and nematodes; sustainable fertilisers of biological origin; biological compost; technologies for improving land and water use and availability and for controlling erosion; climate tolerant animal varieties; aquaculture; and technologies in food processing, conservation, management and storing (e.g., bio-packaging, wooden barrels).

11 Please note that ICE technologies are only considered climate change mitigation technologies when they are primarily aimed at emissions reduction.

Table 5: Top 10 green technological domains in terms of total number of patents, 1975-2017, all countries

Technological domain	Class	Number of patents	% of total patents
Energy storage for electromobility	Y02T10/70	170,591	10.5%
Adaptation technologies in agriculture, forestry, livestock and agroalimentary production	Y02A40	166,126	10.2%
Solar PV	Y02E10/50	133,898	8.2%
Conventional vehicles (ICE)	Y02T10/10	120,623	7.4%
Techniques for reducing energy consumption in wireless communication networks	Y02D70	109,184	6.7%
Climate change mitigation technologies in the production process for final industrial and consumer products	Y02P70	102,932	6.3%
Solar thermal energy	Y02E10/40	97,083	6.0%
Technologies relating to agriculture, livestock and agroalimentary industries[12]	Y02P60	82,079	5.0%
Technologies for wastewater treatment	Y02W10	79,659	4.9%
Energy efficient lighting technologies	Y02B20	75,301	4.6%

Source: Authors

One may wonder whether the most prolific technological classes in terms of patents have changed over time or have always stayed the same. If we consider the most prolific technologies across different time spans (i.e., every 10 years starting in 1975), we see that the top 10 classes in terms of number

12 Relevant technologies included in this class are: agricultural machinery or equipment (e.g., for irrigation, like solar water pumping; motor control; and machines for direct seeding); land use policy measures; afforestation/reforestation; fishing equipment; livestock or poultry management; apiculture; aquaculture combined with aquaponics or hydroponics; and food processing (e.g., storage/conservation and reuse of by-products of food processing for fodder production).

of patents tend to be quite stable, with some minor changes in their ranking. We observe a decreasing role of green technologies related to buildings (Y02B10 and Y02B30) and waste recycling (Y02W30/6 and Y02W30/9) relative to other technologies and an increasing role of technologies for reducing energy in communication networks (see Table 6). This decrease may be associated with these technologies having reached a certain level of maturity.

Table 6: Green patents by selected classes* in selected years as per cent of total patents in each year*

		1975	1985	1995	2005	2015
Y02E10/4	Solar thermal energy	13.0	6.5	3.8	4.5	4.3
Y02A40	Water resources protection and enhancement	12.7	11.6	11.3	6.9	11.7
Y02T10/1	Conventional vehicles (ICE)	11.9	13.4	10.6	9.4	4.4
Y02W10	Technologies for wastewater treatment	10.2	6.9	6.7	4.8	4.0
Y02E10/2	Hydroenergy	6.8	5.4	2.6	2.1	2.2
Y02W30/6	Glass recycling	5.4	2.3	5.3	2.7	1.5
Y02T10/7	Energy storage for electromobility	4.7	3.0	7.8	8.3	9.8
Y02W30/62	Hybrid vehicles	4.2	1.3	3.9	2.1	1.1
Y02B10	Integration of renewable energy sources in buildings	3.9	2.2	2.9	2.7	3.6
Y02B30	Energy efficient HVAC	3.9	5.7	5.3	3.1	3.0
Y02E10/5	Solar PV energy	3.3	10.0	5.8	5.5	7.1
Y02P70	Climate change mitigation technologies in the production process for final industrial and consumer products	2.5	5.3	4.4	7.4	6.1
Y02E60/1	Energy storage	3.1	4.2	3.2	5.5	4.0
Y02P90	Enabling technologies with a potential contribution to GHG emissions mitigation	0.5	3.5	6.6	5.5	4.2

Table 6 (cont.): Green patents by selected classes* in selected years as per cent of total patents in each year*

Y02W30/9	Reuse, recycling and recovery technologies cross-cutting to different types of waste	2.9	3.2	4.5	3.2	2.6
Y02D70	Techniques for reducing energy consumption in wireless communication networks	0.3	0.9	3.2	7.2	9.0
Y02T10/62	Hybrid vehicles	0.8	0.7	2.0	4.9	2.6
Y02P60	Technologies relating to agriculture, livestock and agroalimentary industries	3.5	3.3	2.2	1.9	7.4
Y02B20	Energy efficient lighting technologies	0.5	1.8	2.3	3.4	7.0
Y02T90	Enabling technologies and technologies with a potential or indirect contribution to GHG emissions mitigation	0.7	0.5	2.3	2.0	4.3

Source: Authors

Table 7 shows the top 20 fastest growing domains, of which only one is also among the top 10 most prolific domains (Y02D50 – techniques for reducing energy consumption in wireless communication networks), perhaps a result of fast rates of digitalisation across the world. The growth rate in Table 7 is computed as the average annual growth rate (AAGR) and the selected classes are those that show an above-average AAGR for the period 1975-2015. Wastewater treatment constitutes the fastest growing technology, but different technological classes concerning the reduction of energy consumption in communication networks (including smart grids) (Y02D50, Y02D30) and the provision of energy efficient computing (Y02D70) also represent an important area of technical change. Interestingly, solar thermal-PV hybrids (also known as co-generation) and hybrid vehicles are the fastest growing domains in energy-related and transport-related fields, respectively.

Table 7: Fastest growing green technological classes (classes with an above-average AAGR)

Technological domain	Class	AAGR	Number of patents
Technologies for wastewater treatment	Y02W30/10	59.6%	5,355
Techniques for reducing energy consumption in wire-line communication networks	Y02D50	41.9%	7,070
High-level techniques for reducing energy consumption in communication networks	Y02D30	40.1%	1,083
Smart grids	Y02E40/70	37.4%	5,356
Market activities related to the operation of systems integrating technologies related to power network operation or related to ICT	Y04S50	33.8%	1,785
Technologies relating to industrial water supply, e.g., used for cooling	Y02A20/3	33.2%	720
Solar thermal-PV hybrids	Y02E10/60	32.0%	3,371
Hybrid vehicles	Y02T10/62	20.8%	50,918
Techniques for reducing energy consumption in wireless communication networks	Y02D70	19.4%	109,184
Energy-efficient computing	Y02D10	19.4%	40,045
Technologies related to waste processing or separation	Y02W30/2	17.6%	3,606
Recycling of batteries	Y02W30/84	17.3%	4,215
Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation	Y02B90	16.9%	13,246
Technologies aiming to reduce GHG emissions common to all road transportation technologies	Y02T10/8	16.8%	14,193
Smart grids in the energy sector	Y02E60/7	16.7%	17,062

Table 7 (cont.): Fastest growing green technological classes (classes with an above-average AAGR)			
Systems for electrical power generation, transmission, distribution or end-user application management characterised by the use of ICT, or ICT-specific aspects supporting them	Y04S40	16.2%	16,280
Water resources protection or enhancement	Y02A20/4	15.9%	2,586
Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation	Y02T90	15.7%	66,083
Energy efficient lighting technologies	Y02B20	15.7%	75,301
Enabling technologies with a potential contribution to GHG emissions mitigation	Y02P90	15.4%	74,440
Source: Authors			

A few (but not all) classes are among the top growing in almost all the periods (technologies for wastewater treatment; smart grids[13]; techniques for reducing energy consumption in wireless communication networks; energy efficient computing; and energy efficient lighting technologies). Other classes with a discontinuous growth rate have been growing, particularly in the past few years (e.g., technologies relating to industrial water supply, e.g., used for cooling; technologies aiming to reduce GHG emissions common to all road transportation technologies; smart grids in the energy sector[14]; systems for electrical power generation, transmission, distribution or end-

13 This technology sub-class refers to “systems characterized by the monitoring, control or operation of energy generation units, e.g., distributed generation or load-side generation; systems characterized by the monitoring, control or operation of flexible alternative current transmission systems or power factor or reactive power compensating or correcting units; computing methods or systems for efficient or low carbon management or operation of electric power systems” (USPTO, n.d.).

14 This technology sub-class refers to “systems integrating technologies related to power network operation and communication or IT mediating in the improvement of the carbon footprint of electrical power generation, transmission or distribution, i.e., smart grids as an enabling technology in the energy generation sector” (USPTO, n.d.).

user application management characterised by the use of communication or information technologies, or communication- or information technology-specific aspects supporting them; and water resource protection or enhancement).

Figure 2 maps all the classes by number of patents and AAGR for 1975-2015 and indicates, as expected, a negative correlation between the two variables. Green technologies with a higher number of patents but a low growth rate in innovation suggest that they may have reached a certain level of maturity (such as solar PV, energy efficiency in conventional vehicles and even solar thermal energy).

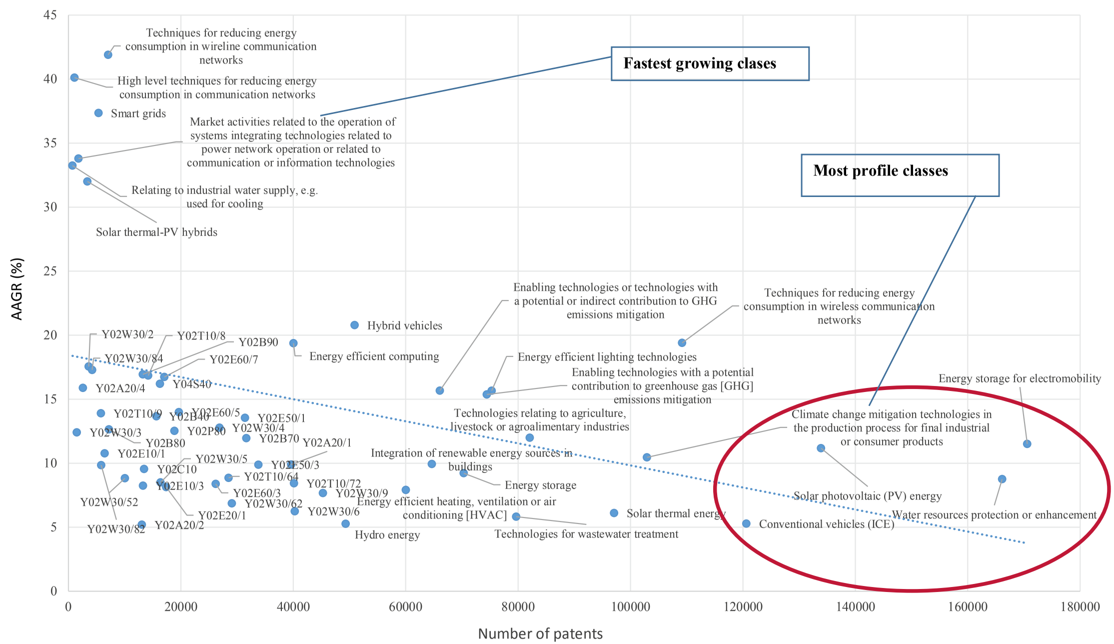
A more condensed summary of Figure 2 is provided in Table 8 below. Technologies with a large number of patents but a slow to medium rate of growth include technologies that have reached a certain level of maturity (and cost reduction), such as solar PV and technologies related to waste collection, transportation, transfer or storage. Other technologies, with low numbers of patents and slow rates of growth in innovation can be considered less mature and may see lower levels of uptake in the next decade. Technologies with further potential in the coming decades may be those with low to medium numbers of patents but with medium to high rates of growth in innovation, such as smart grids, hybrid vehicles or those related to power network operation and ICT.

3.3 Green patenting by countries

In order to examine the country-specific trends, we look at the applicants' country of residence. Two issues are relevant here. First, a patent can have more than one applicant and thus more than one country of residence. To solve this problem, it is common to use the principle of fractional (proportionate) counting.[15] Second, the Patstat dataset is missing some information on the country of applicants. Therefore, in what follows, we use the subset of patents for which we have complete information. The total number of patents is 836,350. As mentioned before, to check for patent quality in parallel to our analysis, we also look at patents that are filed only at the USPTO, which reduces the total number of patents to 312,051.

15 For example, if a patent has three applicants (one from France, one from Germany and one from the United States), each country is assigned one-third of the patent. If a patent has two applicants (one from France and one from Germany), the first applicant, France, is assigned two-thirds of the patent and Germany is assigned one-third.

Figure 2: Green technology classes by number of patents and AAGR, 1975-2015



Note: Class Y02W30/1 (technologies related to waste collection, transportation, transfer or storage, e.g., segregated refuse collecting, electric or hybrid propulsion) has been removed because it displays an AAGR of 59.6%.
Source: Authors

Table 8: Green technology classes by rates of growth in innovation and number of patents (condensed version), 1975-2015

Total number of patents	Rate of growth in patents		
	Slow (<10%)	**Medium (10-25%)**	**High (>25%)**
Large (>100,000 patents)	• Tech. related to waste collection, transportation, transfer or storage • Conventional vehicles • Adaptation tech. in agriculture, forestry, livestock or agro-prod.	• Solar PV • Energy storage for electromobility • Mitigation tech. in the production of final goods • Tech. for reducing energy consumption in wireless communication networks	-
Medium (50,000 – 100,000)	• Solar thermal energy • Hydroenergy • Wastewater treatment • Integration of renewable energy in buildings • HVAC technologies	• Hybrid vehicles • Energy efficient lighting • Tech. relating to agriculture, livestock or agroalim. ind. • Enabling tech. with a potential or indirect contribution to GHG emissions mitigation	-

Table 8 (cont.): Green technology classes by rates of growth in innovation and number of patents (condensed version), 1975-2015

Total number of patents	**Low (<50,000 patents)**	• Marine energy • Combined heat and power, combined cycles • Hydrogen tech. • Electric machine tech. and energy management in electromobility • Water conservation (general water supply and water pollution control tech.) • Tech. for efficient end-user-side electric power management and consumption • Fuel from waste • Reuse, recycling or recovery tech. (all types except batteries) • CO_2 carbon capture and storage	• Smart grids in the energy sector • Geothermal • Biofuels • Energy efficiency in buildings (except HVAC and lighting) • Water resource protection or enhancement • Fuel cells • Tech. aiming to reduce GHG in all road transportation tech. • Waste processing or separation • Landfill tech. aiming to mitigate methane emissions • Bio-organic fraction processing • Recycling of batteries • Climate change mitigation technologies for sector-wide applications • Systems of electrical power gen., transm., distrib. or end-user application management characterised by the use of ICT	• Solar thermal-PV hybrids • Smart grids relating to the energy generation sector in general • Water management (relating to industrial water supply) • Tech. for reducing energy consumption in communication networks • Activities related to operation of sys. integrating tech. related to power network operation or to ICT

Source: Authors

If we look at the top countries in terms of number of patents in the selected green domains, we observe that in addition to the “usual suspects” (United States, Japan and Germany), China, South Korea and Taiwan are leaders (see Table 9). This is true not only when we consider the total number of patents filed in any patent office (i.e., the entire Patstat database), but also when restricting the analysis only to patents applied for at the USPTO.

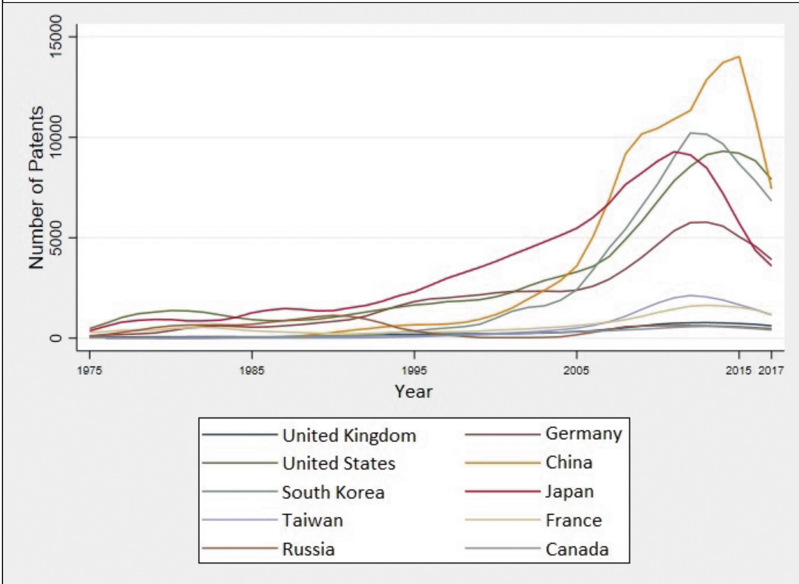
Table 9: Top green patenting countries – cumulative number of patents, 1975-2017, World

All patent offices			USPTO		
Country	**Patents**	**% of total patents**	**Country**	**Patents**	**% of total patents**
Japan	155,501	18.6%	United States	133,219	42.7%
China	148,032	17.7%	Japan	72,837	23.3%
United States	143,145	17.1%	Germany	21,464	6.9%
South Korea	112,699	13.5%	South Korea	19,490	6.3%
Germany	94,927	11.4%	Taiwan	9,441	3.1%
France	27,764	3.3%	France	7,222	2.3%
Taiwan	22,389	2.7%	China	6,238	2.0%
Russia	21,915	2.6%	Canada	6,191	2.0%
United Kingdom	12,813	1.5%	United Kingdom	5,249	1.7%
Canada	9,477	1.1%	Sweden	3,135	1.0%

Source: Authors

Figure 3 shows the trend in the patenting activity of leaders over time and illustrates very clearly both the catching up of China and South Korea and the decreasing green patenting activity of Japan.

Figure 3: Average number of all green patents by year (*t*; *t*-3), by country (leaders)



Source: Authors

This study explores green technology trends in developing and emerging economies. For this purpose, we single out 11 economies that are generally considered "emerging markets" due to their market size and technological capabilities and for which patent data are available: Argentina, Brazil, Chile, China, Egypt, India, Indonesia, Mexico, Russia, South Africa and Turkey. The 2018 Global Competitiveness Index (WEF, 2018) classifies these economies as efficiency driven (i.e., they are in the stage of development when they must begin to develop more efficient production processes and increase product quality because wages have risen and they cannot increase prices) or in transition to being innovation driven (i.e., when higher wages can be sustained only when firms can compete by using highly sophisticated production processes and innovating new ones). The number of green patents for other developing countries, including for example, our case study countries Morocco and Ethiopia, is too small for a meaningful statistical analysis. In the following analysis we, therefore, group the patents for developing countries with other non-OECD countries in the "other non-OECD countries" category.

Table 10 shows how our emerging economies rank in terms of patents. If we look at patents filed in all patent offices, China is in the lead, followed by Russia, Brazil, India and Mexico. At the USPTO, the ranking is similar, but India is ranked higher, while Russia and Mexico hold lower positions. In percentage of total patents, the only country that shows a considerable share is China.

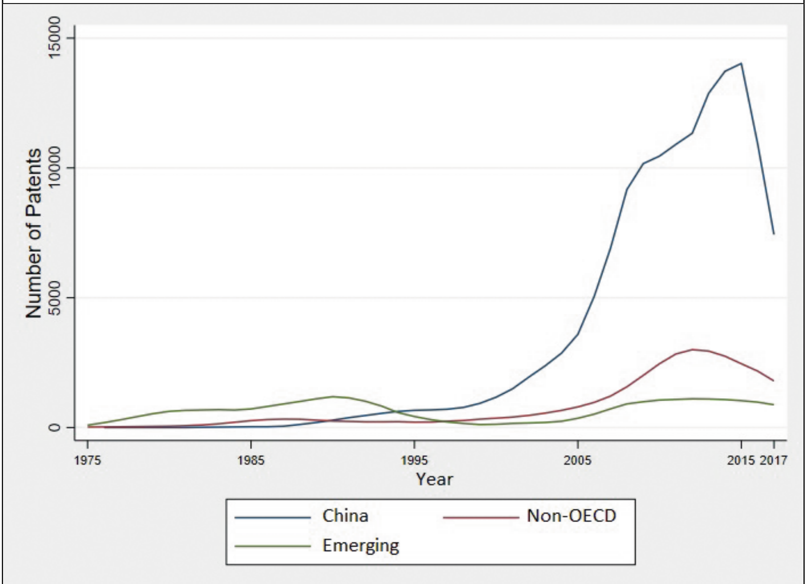
Table 10: Top green patenting emerging countries (number of patents and per cent of total)

All patent offices			USPTO		
Country	**Number**	**%**	**Country**	**Number**	**%**
China	148,032	17.70%	China	6,238	2.00%
Russia	21,915	2.62%	India	1,003	0.32%
Brazil	4,676	0.56%	Brazil	277	0.09%
India	1,663	0.20%	Russia	273	0.09%
Mexico	1,130	0.14%	Mexico	209	0.07%
Turkey	875	0.10%	South Africa	202	0.06%
South Africa	437	0.05%	Turkey	79	0.03%
Argentina	363	0.04%	Argentina	75	0.02%
Chile	267	0.03%	Chile	66	0.02%
Egypt	97	0.01%	Egypt	21	0.01%
Indonesia	35	0.00%	Indonesia	9	0.00%

Source: Authors

Figure 4 shows the average number of (Patstat) patents by year (for each year *t*, the average between *t* and *t*-3) for China, emerging countries excluding China (the same list as in Table 10) and other non-OECD countries. The growing trend in the group of other non-OECD countries is mostly explained by the intense patenting activity of applicants in Taiwan, which is one of the leaders with 22,389 patents. Ukraine (2,205 patents), Singapore (1,710 patents) and Romania (1,355 patents) are the most prolific countries among the other non-OECD countries. All other countries patent significantly less. In fact, a study on green patents in Africa shows that 85% come from South Africa, pointing to the minor role that developing countries still play in (green) technology development (UNEP/EPO, 2013).

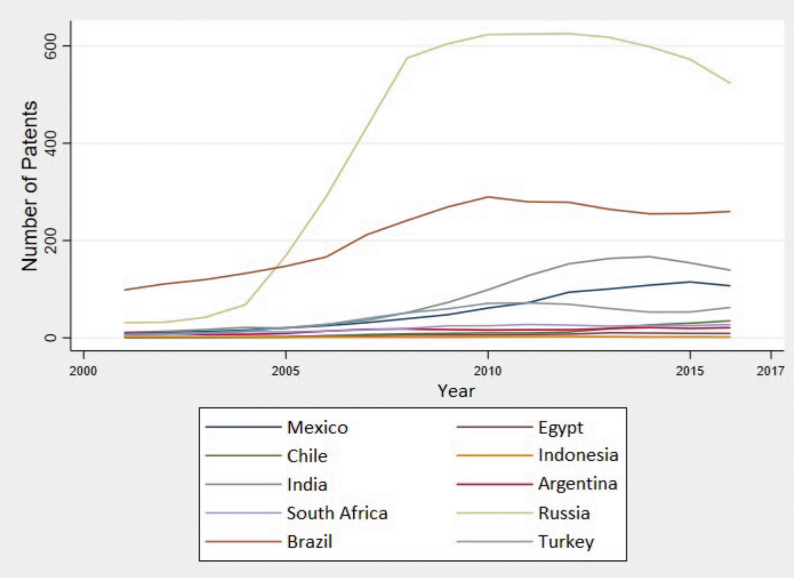
Figure 4: Average number of green patents by year (*t*; *t*-3), by group of countries



Source: Authors

Despite the relatively minor role played by the emerging countries in green innovation as compared with the leaders, we observe an upward trend over the years for most of the emerging countries, as shown in Figure 5. The recent decline is partly due to the lag between patent registration and patent inclusion in Patstat (as discussed earlier) and, to a minor extent, to a recent decline in green patenting activity that may have been by caused by lower public and private investment following the 2008 recession.

Figure 5: Average number of green patents by year (*t*; *t*-3) in emerging countries (excluding China)



Source: Authors

As an additional indicator of the increasing relevance of the patenting activity in the emerging countries, we examine the trends in forward and backward citations, that is, in the citations received by a patent and the citation a patent makes to previous patents, which are well-documented indications of the quality of patents. Both backward and forward citations per patent are increasing in emerging countries and the average number of citations per patent is comparable between leaders and emerging countries, as shown in Table 11.

Table 11: Average number of green patents backward and forward citations per country (emerging and leaders)[16]

Emerging Countries					
	Total patents	**Backward citations**	**Forward citations**	**Backward citations per patent**	**Forward citations per patent**
China	148,032	334,244	373,159	2.3	2.5
Russia	21,915	24,436	18,272	1.1	0.8
Brazil	4676	7,445	4,247	1.6	0.9
India	1663	29,690	16,177	17.9	9.7
Mexico	1130	5,332	2,466	4.7	2.2
Turkey	875	4,027	1,121	4.6	1.3
South Africa	437	5,165	4,472	11.8	10.2
Argentina	363	1,449	1,321	4.0	3.6
Chile	267	2,988	669	11.2	2.5
Egypt	97	1,267	839	13.1	8.7
Indonesia	35	483	317	13.8	9.0
Average	16,317	37,866	38,460	8.0	5.0
Leaders					

16 Several factors may explain the large differences in backward citations across countries. Patent examiners are typically biased in favour of citing applications from their own countries in search reports. Consider also that applications in a specific patent office differ for different applicants: they constitute domestic applications for local applicants but international applications for foreign applicants. There is a positive selection bias for international applications because firms select only their more valuable inventions for protection abroad.

Table 11 (cont.): Average number of green patents backward and forward citations per country (emerging and leaders)

		Backward citations	Forward citations	Backward citations per patent	Forward citations per patent
Japan		1,100,000	1,100,000	7.1	7.1
China		334,244	373,159	2.3	2.5
United States		2,900,000	2,400,000	20.3	16.8
South Korea		366,020	246,683	3.3	2.2
Germany		627,456	488,952	6.6	5.2
France		197,525	135,667	7.1	4.9
Taiwan		116,081	77,035	5.2	3.4
Russia		24,436	18,272	1.1	0.8
United Kingdom		183,720	135,941	14.3	10.6
Canada		158,712	129,729	16.8	13.7
Average		600,819	510,544	8.0	7.0

Source: Authors

Table 12 illustrates the national specialisation patterns for the emerging countries, showing the most relevant technological classes in terms of number of patents. It is interesting to notice that China and Russia have very differentiated technological profiles, with patents in seven out of nine broad technological classes, even if 25 per cent of Chinese patents in the most prolific classes are related to energy technologies, and 26 per cent of Russian patents in the most prolific classes are related to water and agriculture/agroalimentary technologies. On the contrary, the pattern of technological specialisation in Brazil is focussed on energy-related technologies (40 per cent of patents in the most prolific classes) – hydroenergy, solar thermal energy and biofuels – and waste management technologies (27 per cent). Most patents in Indonesia are in water and agriculture/agroalimentary technologies (40 per cent), while India shows a specialisation pattern characterised by patents in green ICT (36.5 per cent) and energy-related technologies (27 per cent).

South Africa, Egypt, Argentina and Chile invest significantly in energy-related technologies, a domain that accounts for almost half of patents in the most prolific classes for all these countries. Mexico and Turkey have a slightly more differentiated pattern of technological specialisation, even though energy-related technologies also play a major role in these countries. Overall, these trends reveal that innovation in green technologies happens mostly where export opportunities exist.

Table 12: The most prolific green patent classes in selected emerging countries (number of patents)

China		Brazil		Indonesia	
Solar thermal energy	15,277	Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	596	Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	10
Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	14,015	Hydroenergy	504	Tech. relating to general water supply	4
Energy efficient lighting	9,815	Solar thermal energy	474	Bio-organic fraction processing; production of fertilisers from the organic fraction of waste or refuse	4
Solar PV energy	9,552	Biofuels	463	Hydrogen technology	4
Tech. for reducing energy consumption in wireless communication networks	9,401	Glass recycling	383	Technologies for wastewater treatment	3

Table 12 (cont.): The most prolific green patent classes in selected emerging countries (number of patents)

Climate change mitigation tech. in the production process for final industrial or consumer products	8,885	Reuse, recycling or recovery tech. cross-cutting to different types of waste	303	Conventional vehicles (ICE)	3
Technologies for wastewater treatment	8,295	Plastics recycling	290	Fuels from waste	2
Energy storage for electromobility	7,419	Technologies relating to general water supply	227	Biofuels	2
Enabling tech. with a potential contribution to GHG emissions mitigation	7,083	Tech. relating to agriculture, livestock or agroalimentary industries	200	Hydroenergy	2
Integration of renewable energy sources in buildings	6,996	Conventional vehicles (ICE)	179	Water pollution control technologies	2
Russia		**India**		**South Africa**	
Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	1,483	Tech. for reducing energy consumption in wireless communication networks	290	Solar thermal energy	64
Conventional vehicles (ICE)	1,014	Energy efficient computing	186	Integration of renewable energy sources in buildings	44

Table 12 (cont.): The most prolific green patent classes in selected emerging countries (number of patents)

Tech. relating to agriculture, livestock or agroalimentary industries	1,000	Energy storage for electromobility	146	Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	43
Reuse, recycling or recovery tech. cross-cutting to different types of waste	759	Solar thermal energy	143	Technologies for wastewater treatment	32
Hydroenergy	643	Solar PV energy	106	Hydroenergy	29
Climate change mitigation tech. in the production process for final industrial or consumer products	462	Biofuels	99	Biofuels	26
Solar thermal energy	450	Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	92	Marine energy	23
Energy storage for electromobility	392	Reuse, recycling or recovery tech. cross-cutting to diff. types of waste	84	Hydrogen technology	22
Glass recycling	346	Technologies for wastewater treatment	81	Reuse, recycling or recovery tech. cross-cutting to different types of waste	21

Table 12 (cont.): The most prolific green patent classes in selected emerging countries (number of patents)

Technologies for wastewater treatment	338	Enabling tech. or technologies with a potential or indirect contribution to GHG emissions mitigation	74	Energy efficient lighting	20
Argentina		**Chile**		**Mexico**	
Hydroenergy	68	Adaptation tech in agriculture, forestry, livestock or agroalimentary production	90	Solar thermal energy	217
Solar thermal energy	42	Hydroenergy	46	Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	166
Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	42	Technologies for wastewater treatment	31	Biofuels	60
Glass recycling	31	Solar thermal energy	29	Technologies relating to general water supply	58
Conventional vehicles (ICE)	29	Marine energy	21	Hydroenergy	55
Plastics recycling	26	Fuels from waste	9	Wastewater treatment	55
Tech. relating to agriculture, livestock or agroalimentary industries	23	Biofuels	8	Tech. relating to agriculture, livestock or agroalimentary industries	51

Table 12 (cont.): The most prolific green patent classes in selected emerging countries (number of patents)

Marine energy	20	Reuse, recycling or recovery tech. cross-cutting to different types of waste	7	Integration of renewable energy in buildings	51
Reuse, recycling or recovery tech. cross-cutting to different types of waste	15	Energy storage	7	Glass recycling	48
Biofuels	12	Conventional vehicles (ICE)	7	Conventional vehicles (ICE)	46

Egypt		**Turkey**	
Tech. relating to general water supply	28	Solar thermal energy	212
Solar thermal energy	26	Adaptation tech. in agriculture, forestry, livestock or agroalimentary production	82
Hydroenergy	10	Hydroenergy	81
Solar PV energy	9	Energy efficiency for home appliances	63
Water pollution control technologies	8	Tech. for reducing energy consumption in wireless communication networks	46
Integration of renewable energy in buildings	8	Energy efficient HVAC	43
Marine energy	8	Energy storage for electromobility	38
Technologies for wastewater treatment	6	Marine energy	38
Energy efficient HVAC	6	Solar PV energy	34
Energy efficient lighting	4	Energy storage	33

Source: Authors

3.4 Summary

Understanding past and current trends in green innovation allows us to better comprehend what the future holds in terms of which technologies are likely to play a role in the transition to a green economy. Our analysis showed that developed and emerging economies are leading in terms of green technology development. Not surprisingly, developing countries and the rest of the world play a minor (though increasing) role in green technology innovation. Analysing worldwide patenting trends is nevertheless relevant for the NQI systems in developing countries; these trends provide a good proxy of global technology use, which affects developing countries directly when they import or license technology. Patent analysis, therefore, reveals which technologies are likely to be used for greening the economies of developing countries.

Green technologies have seen fast rates of innovation (as measured by patent data) between 1975 and 2017, especially after 2005. The rate of growth in green innovation has been much faster than for other technologies, signalling that the transition to a green economy is well underway. Innovation in some technology sectors has been quite dynamic as reflected by the large number of patents (such as in energy-generation-related technologies, transport-related technologies, and production-related technologies (e.g., energy efficiency in industrial processes), or energy efficiency in buildings, solid waste management, and technologies related to adaptation to climate change). In other technology sectors (such as carbon capture and storage) innovation has lagged behind. Yet others have recently seen fast rates of growth in patenting activity, such as technologies related to ICT, power operation networks (i.e., smart grids), and water resources protection and enhancement, despite the fact that they represent a smaller share of the total number of green patents. These technology families are the ones where a lot of innovation is expected to happen in the coming decade, especially due to the advance of digitalisation. Overall, the fastest growing green technology classes are wastewater treatment, techniques for reducing energy consumption in communication networks, solar thermal-PV hybrids (co-generation) and hybrid vehicles. These are also green technologies that are considered important for greening economies in the developing countries.

At a more disaggregated level, energy storage for electromobility is one of the technologies that has seen the greatest number of patents, followed by adaptation technologies in agriculture, forestry, livestock or the agroalimentary sector, solar PV energy, and energy efficiency in conventional vehicles. As technologies reach a certain level of maturity we observe, over time, a decrease in patenting activity, and we expect to see faster rates of deployment as costs come down. These trends can be observed for technologies related to energy generation (such as solar PV and other renewables), waste recycling and energy efficiency related to buildings. This evolution also corresponds with the expected market trends for the next decade (as we will discuss in Chapter 4).

Not surprisingly, most technology development in the green sectors was done in developed countries, particularly in Japan, the United States and Germany; but we observed a shift in green innovation from Europe and North America to East Asia, with China, South Korea, and Taiwan playing an increasingly important role in global technology development. Moreover, in the emerging economies group, China leads, followed by India, Russia, Brazil, Mexico, South Africa and Turkey.

A critical observation is that an increasing trend in green patenting activity is also seen in non-OECD/non-emerging countries, especially after 2005; yet, the number of patents remains small, especially in developing countries.[17] In this group of countries (non-OECD/non-emerging) some of the most dynamic green innovation sectors have been renewable energy (specifically solar PV, solar thermal and hydroenergy), followed by adaptation technologies in agriculture, forestry, livestock or agroalimentary production; energy efficiency in industrial processes; energy efficient computing and energy consumption reduction in communication networks; and energy efficient lighting technologies.

Furthermore, it is interesting to note that the national specialisation in green innovation among emerging economies varies and is closely aligned with sectors with strong comparative advantage and export opportunities. Not surprisingly, given China's increasing global role in manufacturing of renewable energy technologies, most green patents in China are in energy technologies. Most green patents in Brazil relate to energy-related technologies, such as hydroenergy, biofuels and solar thermal energy, and waste management technologies. India shows a specialisation pattern in green ICT and energy-related technologies. Mexico and Turkey have slightly

17 In this category Ukraine, Singapore and Romania (which are non-OECD/non-emerging countries) have the largest number of green patents, while developing countries still have a negligible number of patents.

more differentiated patterns of technological specialisation, even if energy-related technologies play an important role here too.

Overall, the green patents analysis highlighted that emerging economies are particularly well positioned to advance in the transition to a green economy. Developing countries, however, lag behind in innovation. Yet, fast rates of innovation in green technologies related to, for instance, electricity generation and transportation, contributed to cost reductions. We would expect, therefore, to see fast rates of diffusion for a range of green technologies in developing countries too, creating the need to build capabilities related to QI.

4 Expected trends in the transition to a green economy and implications for QI

Having gained a better understanding of which green technologies have seen fast rates of development in the past decades and how these trends have been geographically distributed, we turn our attention now to what the future holds regarding greening economies. In this chapter, we seek to examine which families of green technologies are likely to see faster rates of deployment in the coming decade and to what extent we can expect to see domestic value creation and technological learning. As technologies vary in terms of their degree of sophistication, we expect to see variations in local value creation and technological learning that would reflect local technological capabilities for different levels of technology sophistication. Further, we are interested in assessing what these market trends mean in terms of required QI capabilities for the various families of green technologies.

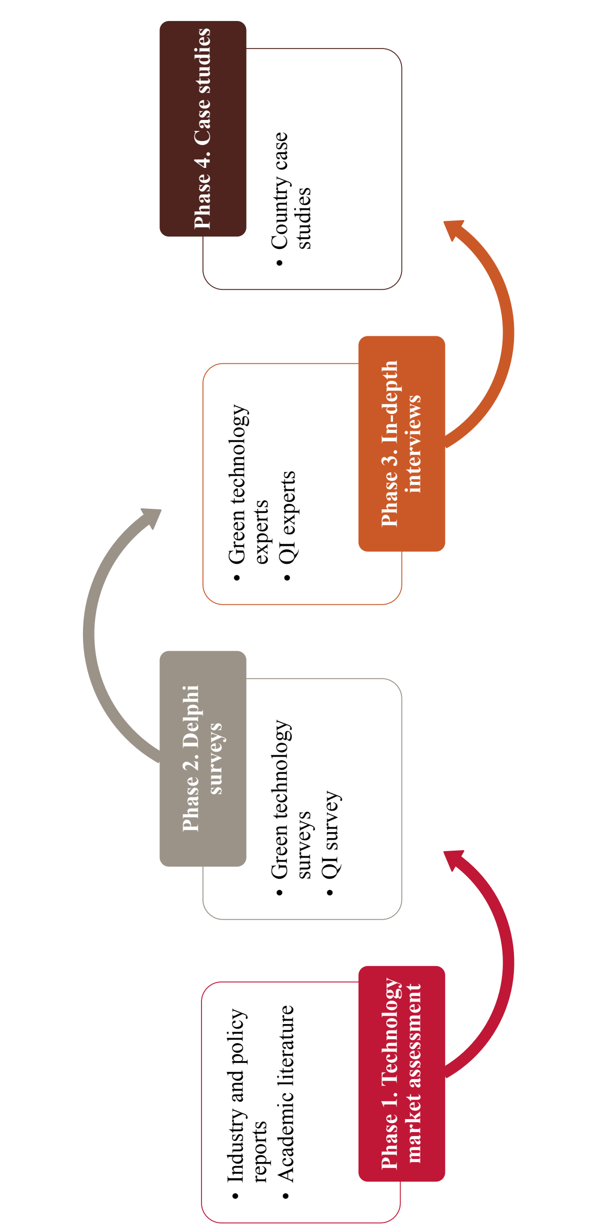
We start by introducing the research design we used to assess the questions above (Section 4.1). In Section 4.2, we discuss in detail our findings regarding expected trends towards greening the economies of developing and emerging countries, both in terms of market development (i.e., technology deployment) and opportunities to build up domestic capabilities. Section 4.3 summarises the main findings. We then turn our attention to QI implications. In Section 4.4, we discuss these findings in detail, and we summarise in Section 4.5

4.1 Research design

To explore these aspects, we rely primarily on qualitative research methods. Due to the nature of the questions asked (future trends and implications for needed capabilities) and the complexity of the issues in focus, we combine different approaches for collecting and analysing our data (see Figure 6). We started with a technology market assessment by reviewing academic literature, and industry and technology reports to understand which families of green technologies are likely to be most relevant to greening the economies of developing countries (Phase 1). Since this study is future oriented and focusses on uncertain processes and trends, we decided to use the Delphi survey as a tool to explore both trends in market developments and implications for needed QI capabilities (Phase 2). We discuss this method in more detail below. To supplement the information obtained from the surveys and better understand differences in trends related to specific technologies, we also conducted in-depth interviews with a select number of technology experts (Phase 3). Lastly, three country case studies were conducted to examine expected trends in greening their economies in core sectors and the challenges and opportunities associated with building QI capabilities to support these developments (Phase 4, discussed in more detail in Chapter 5).

To explore the uncertain future, few methods are available to researchers. One such method is the Delphi survey, widely accepted and frequently used for future-oriented studies on technical developments and trends relying on forecasting by experts. The Delphi method is a systematic, multi-stage and interactive method of eliciting and collating informed judgements on complex matters where precise knowledge is not available. The Delphi method usually involves circulating a series of sequential questionnaires (also called Delphi rounds) to a panel of experts on the subject of consideration, with each Delphi round building on the results of the previous one (Breiner, Cuhls, & Grupp, 1994; Georghiou, 1996; Landeta, 2006). Earlier research suggests that Delphi outperforms other group formats, such as statistical groups or standard interacting groups, in terms of effectiveness (Rowe & Wright, 1999; von der Gracht, Vennemann, & Darkow, 2010). According to Rowe, Wright and Bolger (1991), four main characteristics of the Delphi method can be identified: anonymity in the process; controlled feedback; statistical aggregation of group responses; and iteration.

Figure 6: Mixed methods approach



Source: Authors

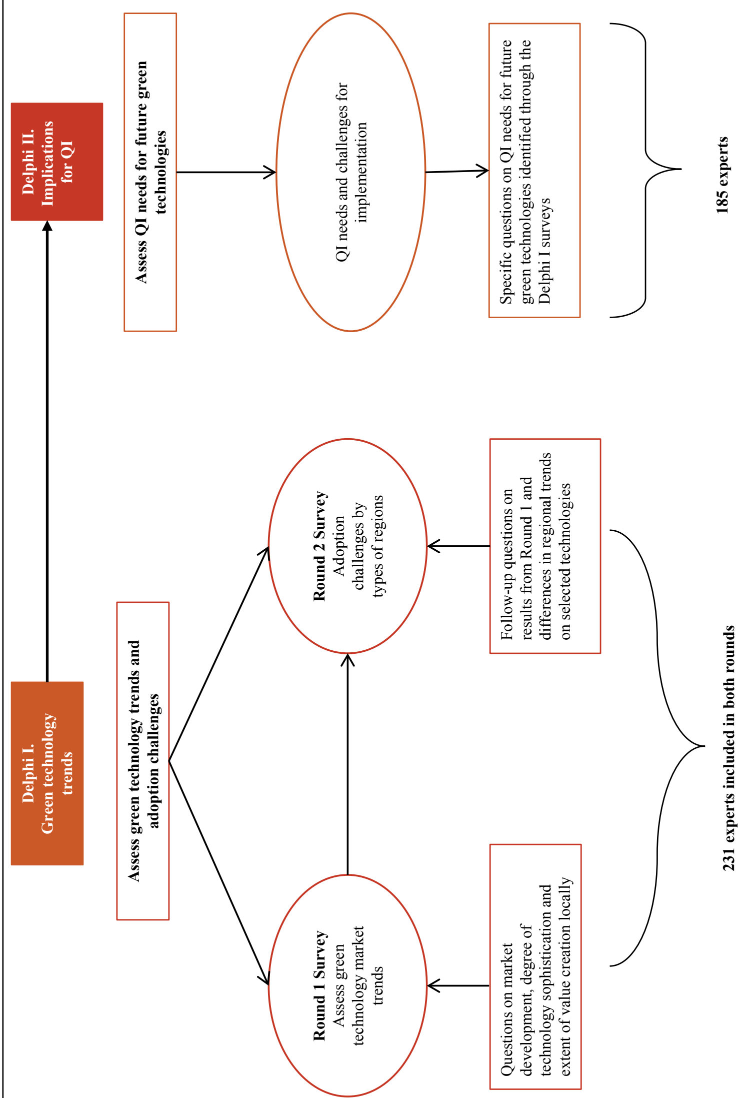
Since the outcome of the Delphi survey is largely dependent upon the composition of the expert panel, it is essential that the participants be appropriately selected. Expert selection is the most important step in the entire process because it relates directly to the quality of the results generated. In addition, one success factor for Delphi studies appears to be the heterogeneity of the panelists. It is believed that diversity ensures a wide spectrum of opinions and judgements, thereby reducing potential sources of bias (Rowe, 1994).

Moreover, the implementation of Delphi surveys has recently been facilitated by online platforms. Such platforms allow not only easy and quick access to the survey questions for the experts, but they also enable experts to have real-time access to the opinions provided by other participants, thus contributing to so-called "co-creation" of knowledge. Following a review of several tools (Aengenheyster et al., 2017) and exchange with various experts on this method, we decided to use the Surveylet tool developed by Calibrum Surveys. Surveylet is a fully professional tool that can support both large- and small-scale real-time Delphi surveys, so-called "Intelligent Surveys" (Aengenhyster et al., 2017). Surveylet allows for different types of questions and results to be presented in different forms (numbers, percentages and charts).

The expert panel has been carefully selected to include international experts in the fields of green economy, innovation policy and technology studies, green technologies and QI. Drawing on contacts from both the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE) and the PTB as well as other renowned experts in these areas, we assembled a database of 371 experts. Since only few professionals possess expertise in both QI and a broad range of green technologies and innovation studies, we separated the database into two main groups: (a) green economy, innovation studies and green technology expertise (a total of 231 experts); and (b) QI (a total of 185 experts).

For this main reason, we also decided to use a more pragmatic approach to the Delphi study, by designing and implementing two separate surveys: (1) a survey on green technology trends and (2) a survey on implications for QI infrastructure needs (see Figure 7). The surveys were implemented between April and October 2018 and each round was open for a maximum of two months. Given the complex technical and engineering details of most green technologies, we also conducted several in-depth interviews with technology experts after the first and second rounds of "Delphi I" (see Figure 6) to better understand the resulting trends.

Figure 7: Research design for Phase 2 – the Delphi surveys



Source: Authors

The surveys explore the trends of interest for both emerging and developing countries. Following the selection criteria explained in Chapter 3, we include the following countries in the emerging economies category: Argentina, Brazil, China, Chile, Egypt, India, Indonesia, Mexico, Russia, South Africa and Turkey. The developing countries category includes all other non-OECD countries.

4.2 Trends in green technologies: deployment and domestic capabilities

As Figure 7 illustrated, we conducted two survey rounds to assess trends in green technology deployment and opportunities for local value creation. Round 1 of the green technology survey included three core questions:

- Do you expect that between now and 2030 markets for green technologies in emerging and/or developing countries will develop slowly, moderately or rapidly?
- How do you rate the degree of sophistication of the related technologies?
- Do you believe that between now and 2030 emerging/developing countries will provide: (a) a low level (<30 per cent); (b) a medium level (30-70 per cent); or (c) a high level of domestic value added and technological capabilities?

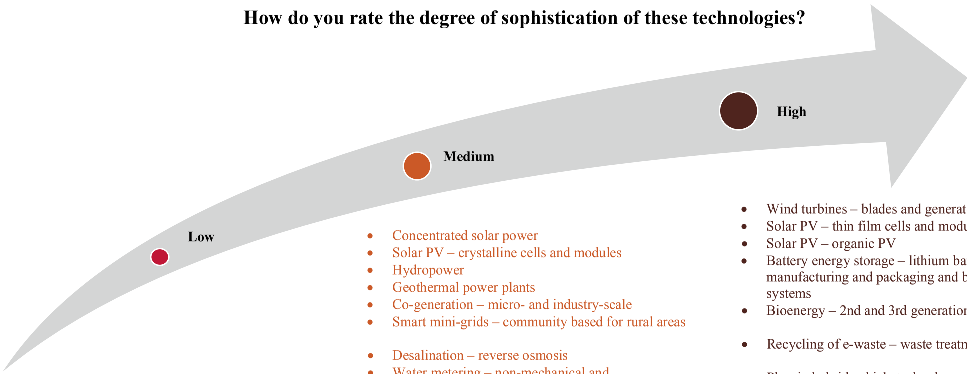
Round 2 of the survey aimed to validate the results from the first survey and to ask a series of open questions on specific related aspects. The list of questions used in the second survey round can be found in Table A2 in the Appendix.[18]

As Figure 8 illustrates, there is wide variation between green technologies in terms of the degree of sophistication of related technologies. Also, within the same family of technologies, such as solar energy technologies, the sophistication of technologies varies across the entire spectrum. For example, solar water heaters have a low level of sophistication, while crystalline solar PV cells and modules have a medium degree of sophistication, and organic PV and thin film solar PV cells and modules are highly sophisticated technologies. Similarly, manufacturing wind towers is less technologically sophisticated, while the turbine blades and generators are complex and require a high level of precision.

18 The response rates for the survey were 35 per cent and 23 per cent for the first and second rounds, respectively.

Figure 8: The degree of sophistication of green technology families

How do you rate the degree of sophistication of these technologies?



Low

- Wind turbines – towers
- Solar water heaters
- Geothermal – ground source heat pumps
- Bioenergy – 1st generation biofuels

- Residential grey water re-use systems
- Wastewater treatment – municipal sewage treatment
- Rainwater harvesting
- Water metering – mechanical

- Recycling of e-waste – mechanical separation

- Solar lanterns
- Ethanol cookstoves
- Solar cookers
- Solar water pumps
- No-till cropping and agroforestry to prevent soil erosion

Medium

- Concentrated solar power
- Solar PV – crystalline cells and modules
- Hydropower
- Geothermal power plants
- Co-generation – micro- and industry-scale
- Smart mini-grids – community based for rural areas

- Desalination – reverse osmosis
- Water metering – non-mechanical and electromechanical*

- Recycling of paper, glass, aluminium

- Composting
- Methane capture at landfills

- Electric engines and simple electric cars^

- Smart meters
- HVAC systems
- Solar electric cooling
- Solar thermal cooling

- Household biogas digesters
- Bioremediation (soils and water)
- Precision agriculture

High

- Wind turbines – blades and generators
- Solar PV – thin film cells and modules
- Solar PV – organic PV
- Battery energy storage – lithium battery cell chemistry, manufacturing and packaging and battery management systems
- Bioenergy – 2nd and 3rd generation biofuels

- Recycling of e-waste – waste treatment and processing

- Plug-in hybrid vehicle technology
- Hydrogen fuel cell vehicles

- LED lamp production

- GM crops – genetic engineering for fuel production and carbon sequestration
- CRISPR/Cas to enhance resilience of food crops to changing climate

- Carbon capture, utilisation and storage

Note: (*) denotes medium to high sophistication, (^) denotes low to medium sophistication
Source: Authors

This variation in the degree of technological sophistication adds more complexity to our analysis but it also allows us to better understand why some technologies are likely to be diffused faster than others and why some countries are likely to develop more capabilities in some groups of technologies but not in others. The variation of sophistication within the same group of technologies also calls for caution in discussing future trends, especially when it comes to domestic value added and technological capabilities. Specifically, at this higher level of aggregation (global and regional studies across a wide variety of technologies) it becomes difficult to derive solid and concrete estimates of opportunities for localisation and innovation unless one disaggregates technologies at a more granular level. It is for this reason that we narrow down our study to a few country case studies and technologies (see Chapter 5) that will allow us to examine such implications more concretely and derive conclusions with a higher degree of validity and reliability. Without a certain degree of aggregation we would not be able to distinguish more general trends and make longer-term strategic policy recommendations.

Our results reveal some interesting trends in terms of market development and opportunities for local value creation and technological capabilities by 2030, as illustrated in Figures 9 to 12.

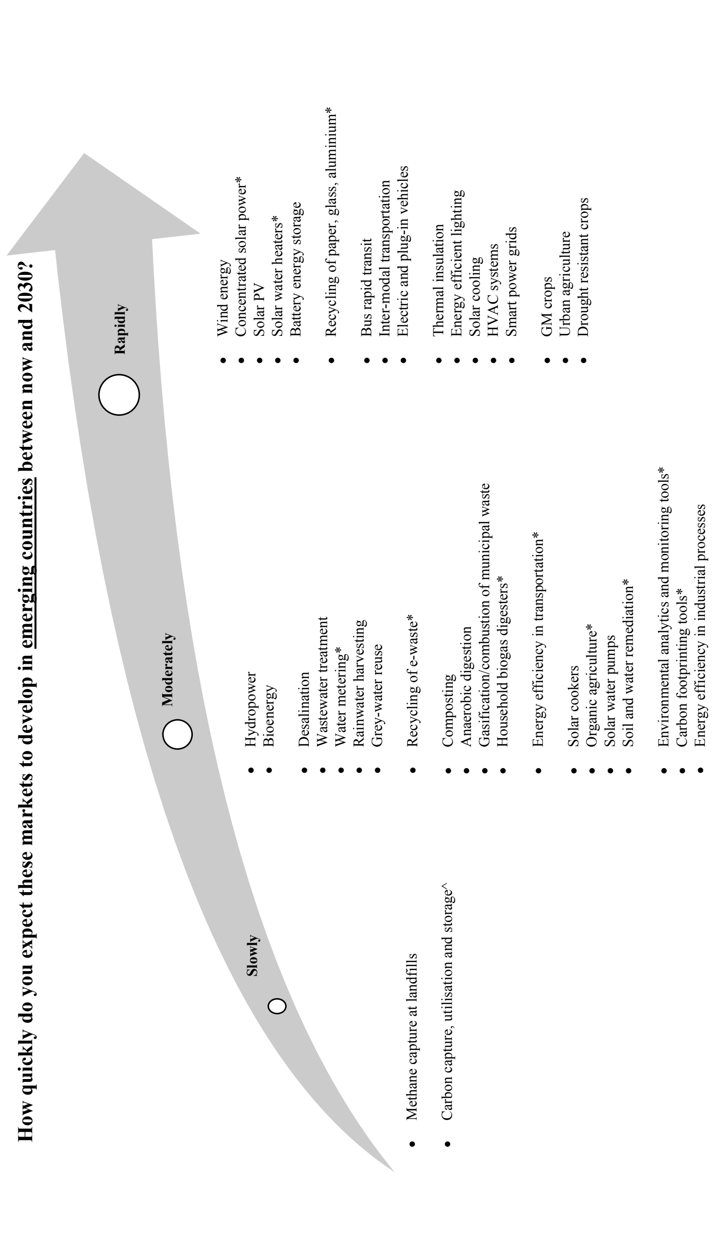
Emerging economies are likely to see moderate to rapid market growth in all green technologies (with only a few exceptions). Here, domestic value addition and technological capabilities are expected to be more than 30 per cent (medium to high) and higher in some sectors, such as transportation. Developing countries, by contrast, are likely to see rapid market development only in selected technologies, such as solar PV and recycling of paper, glass and aluminium, but moderate growth in a large number of other green technologies, such as wind energy, biomass, water management and thermal insulation. Markets for more complex and sophisticated technologies, such as concentrated solar power (CSP), electric and plug-in vehicles, recycling of e-waste, and organic agriculture are likely to see little dissemination and low domestic value added. Aside from cost levels and technological sophistication, the institutional framework (e.g., incentives, implementation and enforcement) is seen as an important determining factor for the speed of market development in developing countries. Below, we discuss these findings in more detail.

4.2.1 Emerging economies

Emerging economies are likely to see moderate to rapid market growth in most technology sectors (see Figure 9), such as electricity (in particular wind energy, solar PV, CSP, solar water heaters (SWHs)), as well as waste management, transportation, energy efficiency in buildings and industrial processes, agriculture, and soil and water remediation. Respondents argue that wind energy technologies, solar PV, and SWHs have seen significant cost digressions, have reached market maturity and in countries such as China and India have already been widely deployed. For currently more expensive electricity generation technologies, such as CSP, cost reductions are expected especially because of stricter environmental regulation (necessary due to increasing air pollution in the urban areas), commitment to decarbonisation, and increasing costs for conventional energy technologies. Important to mention, however, is that while these trends appear undisputed in countries like China and India, it remains to be seen whether other emerging countries will follow suit. Respondents suggest that Mexico, for example, is likely to see similar trends in wind and solar energy technologies, but Russia is not.

The degree of sophistication of related technologies varies in the electricity generation sector, with SWH having a low technological sophistication, wind and solar a medium level, and battery energy storage a high level of sophistication (see Figure 8). Thus, even if markets are expected to grow rapidly for solar and wind technologies, for example, less than 30 per cent of value added for CSP is expected to be provided locally, while for wind energy, solar PV and SWH 30-70 per cent will be provided locally (see Figure 10). These outcomes can be traced back to differences between these technologies in terms of their sophistication; CSP and solar PV (the crystalline cells and modules) having a medium level of sophistication, while SWH and the towers for wind turbines have a low level of sophistication. In comparison with the crystalline solar PV technology that has seen fast cost reductions and thus high rates of deployment over the past decade, CSP is a less mature technology and much more costly, thus its domestic value added is also expected to be lower.

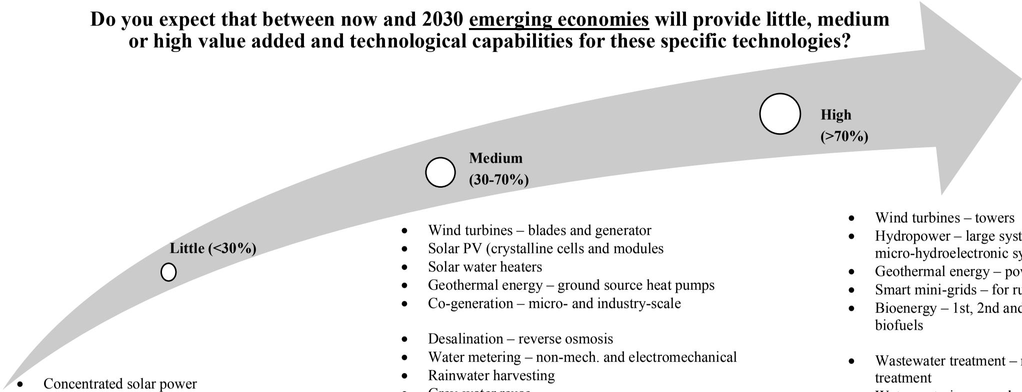
Figure 9: Expected trends in market development for selected green technologies in emerging economies



Note: (*) denotes moderate to rapid development, (^) denotes low to moderate development
Source: Authors

Figure 10: Level of domestic value added and technological capabilities to be provided in emerging economies by 2030

Do you expect that between now and 2030 emerging economies will provide little, medium or high value added and technological capabilities for these specific technologies?



Little (<30%)

- Concentrated solar power
- Solar PV (thin film cells and modules and organic PV)
- Battery energy storage (lithium battery cell and battery management systems)

- Methane capture at landfills

- Plug-in hybrid vehicle technology
- Hydrogen fuel cell vehicles

Medium (30-70%)

- Wind turbines – blades and generator
- Solar PV (crystalline cells and modules
- Solar water heaters
- Geothermal energy – ground source heat pumps
- Co-generation – micro- and industry-scale

- Desalination – reverse osmosis
- Water metering – non-mech. and electromechanical
- Rainwater harvesting
- Grey-water reuse

- Recycling of paper, glass, aluminium
- Recycling of e-waste – treatment and processing
- Composting

- Smart meters
- HVAC systems

- Household biogas digesters
- Solar cookers
- Ethanol cookstoves

- GM crops – genetic eng. for fuel prod. and carbon sequestration
- Genome editing – CRISPR/Cas to enhance resilience of food crops to changing climate
- Bioremediation (soils and water)

- Carbon capture, utilisation and storage

High (>70%)

- Wind turbines – towers
- Hydropower – large syst. with dams and micro-hydroelectronic syst.
- Geothermal energy – power plants
- Smart mini-grids – for rural areas
- Bioenergy – 1st, 2nd and 3rd generation biofuels

- Wastewater treatment – municipal sewage treatment
- Water metering – mechanical

- Recycling of e-waste – mech. separation

- Electric engines and simple electric cars

- Energy efficient lighting – LED lamp production and solar lanterns
- Solar electric and thermal cooling

- Solar water pumps
- No-till cropping and agroforestry to prevent soil erosion
- Precision agriculture

Source: Authors

All forms of recycling technologies (e.g., paper, glass, aluminium and e-waste[19]) are expected to see moderate to rapid market growth in emerging economies. As most experts argued, markets for paper, glass and aluminium are already well developed in these countries; the large-scale recycling of e-waste will, however, depend highly on favourable regulatory frameworks (adequate policies and enforcing mechanisms) and awareness programmes. The technological sophistication of related technologies is low to medium (except for the treatment and processing of e-waste) and emerging economies still benefit from lower labour costs.[20] Thus, the Delphi experts estimate that emerging economies are likely to provide up to 70 per cent of domestic value added and capabilities for recycling technologies (paper, glass, aluminium and treatment and processing of e-waste) and more than 70 per cent for the mechanical separation of e-waste (see Figure 10). Moreover, these shares are expected to increase in the future.

Markets for green technologies related to transportation are also expected to grow rapidly in emerging economies (see Figure 9). Increasing population density and pollution levels in urban areas will demand alternative modes of transportation. Bus rapid transit, inter-modal transportation systems and electric vehicles are considered growing markets in these countries, although challenges are foreseen in rolling out these technologies (e.g., city planning, infrastructure, regulations and a paradigm shift in transportation culture). Plug-in hybrid electric vehicles and fully battery electric vehicles are expected to become cost-competitive in the next 10 to 15 years. Polluted megacities in China will be main drivers, while other polluted cities will also encourage clean transport fleets (emissions standards, mandatory electric bus and taxi fleets, etc.). However, large regional differences are expected with China, for example, leading the way across several technologies and Brazil leading in ethanol fuels. Interesting here is that although electric and plug-in vehicles have a high degree of technological sophistication (see Figure 8), emerging economies are expected to provide more than 70 per cent of value added and technological capabilities domestically. In this particular sector, China stands out (Altenburg, Feng, & Shen, 2017), while other emerging economies experience very different patterns, ranging from medium- to high levels of domestic value added, on the basis of foreign

19 For the recycling of building materials, we had too few responses to be able to identify a clear trend.

20 For example, China and India both have the appropriate policies in place, but while China has enforced them, India has not managed to.

direct investment (FDI) and technology licensing. Hence, technological capabilities are expected to be limited to second- and third-tier suppliers and after-market services. Local value added and technological capabilities for plug-in hybrid vehicles and hydrogen fuel cell vehicles are expected to remain low (less than 30 per cent).

Energy efficiency in buildings is another technology sector likely to see rapid market growth between now and 2030 (see Figure 10), driven primarily by objectives to reduce cost and energy consumption. The technological sophistication of these technologies is considered medium and most countries have already made important progress (in terms of market development and domestic capabilities) in this sector. Available technical skills and low wages will also ensure that these countries can provide high levels of value added and technological capabilities (more than 30 per cent and for some technologies more than 70 per cent, as Figure 10 illustrates).

All agriculture and soil and water remediation technologies included in our study are also expected to disseminate moderately to rapidly in emerging economies in the coming decade, in particular the use of GM crops, urban agriculture and drought resistant crops. For organic agriculture, experts did not reach a full consensus on how fast markets are going to develop. Experts have argued that for organic agriculture markets to develop, value addition (through transformation, packaging, etc.) as well as technological capabilities applied to innovation in production and processing are necessary. According to our experts, such know-how is available in most emerging economies and is provided by higher education institutions and in many cases by state agricultural extension agencies. The question is if the economic dynamics of production and consumption will generate the necessary incentives for these technologies to disseminate on a large scale.

A number of other green technologies are likely to experience moderate market development, such as hydropower, bioenergy, various water management technologies, most waste management technologies, energy efficiency in industrial processes and others such as carbon footprinting tools and environmental analytics. Most of these technologies are considered to have a low- to medium level of technological sophistication and emerging economies are expected to provide medium- to high levels of domestic value added and technological sophistication. Regarding hydropower, for example, experts argue that emerging economies are considered technology providers for developing countries. The demand for bioenergy is also high in these countries and technologies are widely available, but markets are constrained by public policy. The degree of technological sophistication will be low initially, but it will grow as the markets develop (e.g., second generation biomass technologies require biotech; the utilisation of bio-based inputs in production will increase the level of sophistication of products, as these are expected to be driven by R&D activities). Thus, the required technologies will grow as the degree of sophistication of the products improves. For this reason, emerging economies are expected to provide medium- to high levels of domestic value added and technological capabilities by 2030 (see Figure 10).

Wastewater treatment is also likely to see only moderate market development despite the perceived strong need in the growing urban centres of emerging economies. One reason behind this expected trend provided by several experts is the policy framework, which, if "well implemented" could lead to rapid market development. The case of India is illustrative, where although technological options exist, market development has been hampered by poor regulatory enforcement (Never, 2016). Steps have been taken to correct these failures and put in place much-needed skill development programmes, but progress in the medium and long term appears slow and systemic interventions are lacking.

Markets for combustion or gasification of municipal solid waste are likely to grow mostly due to an increase in demand, but progress depends on effective legislation and emissions control. Moreover, gasification and incineration plants are very expensive (and the level of technological sophistication of related technologies is very high, see Figure 8), so other more cost-effective waste management systems should be prioritised.

With the advance of global climate agreements, carbon footprinting tools, which have a low degree of technological sophistication are also expected to be increasingly used in emerging economies. Emerging countries could see a niche sector for consulting services and related technologies emerging in this field if public policy supports these technologies. Experts suggest that such tools are already increasingly used in different emerging countries in Latin America, for instance.

Lastly, the results from our Delphi survey suggest that between now and 2030, markets for carbon capture and storage and methane capture at landfills will develop only slowly in emerging economies. With regards to the latter, a lack of financing mechanisms and other incentives and the need for economies of scale are expected to restrict market development in the future.

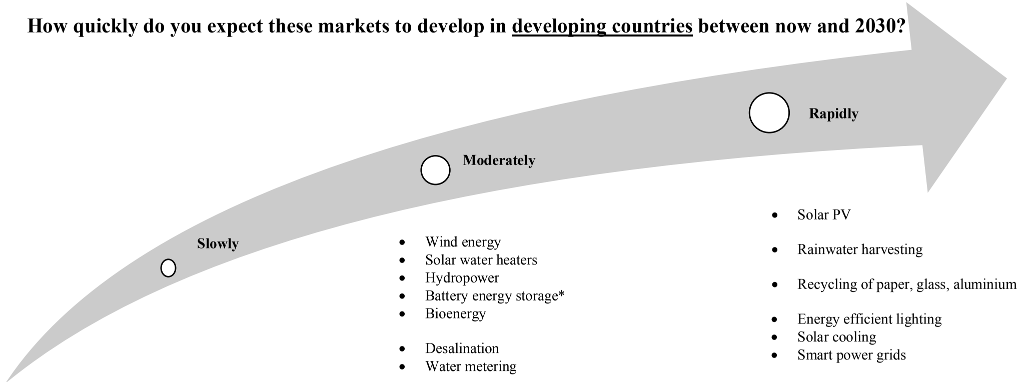
4.2.2 Developing countries

In contrast to emerging economies, developing countries are likely to see rapid market development only in selected technologies. Specifically, our Delphi survey suggests that markets for solar PV, rainwater harvesting, recycling of paper, glass, and aluminium, some technologies in the energy efficiency in buildings family, urban agriculture and drought resistant crops are likely to grow rapidly in these countries (see Figure 11). Less consensus exists on whether markets will develop rapidly or moderately for battery energy storage, composting, BRT and HVAC systems. A host of other green technologies are, however, expected to see moderate market development in developing countries.

Significant cost declines for solar PV technologies and the lower level of sophistication of related technologies enable developing countries to deploy and adopt this technology at large scale. The level of technological sophistication varies, however, between crystalline silicon-based solar PV or thin-film technologies (see Figure 8). Diffusion in developing countries is therefore likely to be higher for more mature solar PV technologies. But diffusion also depends on supportive policies, finance and implementation and maintenance processes (e.g., quality assurance), which might lag behind in low-income countries. For all these reasons, developing countries are likely to see up to 70 per cent of value added and technological capabilities being provided locally (see Figure 12) (less where the institutional framework is weak, as per the Delphi experts). Domestic contribution will vary from one country to another and may come more in the supply of ancillary products in the solar power systems (so called "balance of systems"), such as mounting structures and wires, and less in solar cells, modules and batteries.

Figure 11: Expected trends in market development for selected green technologies in developing countries

How quickly do you expect these markets to develop in <u>developing countries</u> between now and 2030?



Slowly

- Concentrated solar power

- Wastewater treatment^
- Grey-water reuse^

- Recycling of e-waste^

- Anaerobic digestion
- Methane capture at landfills

- Electric and plug-in vehicles^
- Hydrogen fuel cell vehicles

- Solar cookers
- Organic agriculture
- Genome editing

- Carbon capture, utilisation and storage

Moderately

- Wind energy
- Solar water heaters
- Hydropower
- Battery energy storage*
- Bioenergy

- Desalination
- Water metering

- Gasification/combustion of municipal waste
- Composting*

- Bus rapid transit*
- Inter-modal transportation
- Energy efficiency in transportation

- Thermal insulation
- HVAC systems*

- Household biogas digesters
- GM crops
- Solar water pumps
- Soil and water remediation*

- Environmental analytics and monitoring tools
- Carbon footprinting tools

- Energy efficiency in industrial processes

Rapidly

- Solar PV

- Rainwater harvesting

- Recycling of paper, glass, aluminium

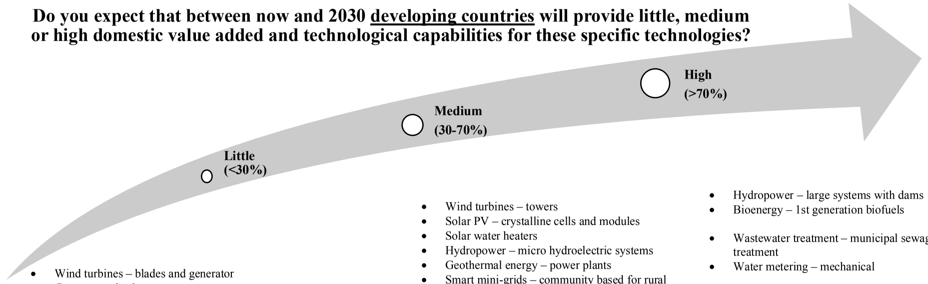
- Energy efficient lighting
- Solar cooling
- Smart power grids

- Urban agriculture
- Drought resistant crops

Note: (*) denotes moderate to rapid development, (^) denotes low to moderate development
Source: Authors

Figure 12: Level of domestic value added and technological capabilities to be provided in developing countries by 2030

Do you expect that between now and 2030 developing countries will provide little, medium or high domestic value added and technological capabilities for these specific technologies?



Little (<30%)

- Wind turbines – blades and generator
- Concentrated solar power
- Solar PV – thin film and organic PV
- Geothermal energy – ground source heat pumps
- Battery energy storage
- Co-generation – micro- and industry-scale

- Desalination – reverse osmosis
- Water metering – non-mechanical and electromechanical
- Greywater reuse

- Recycling of paper, glass, aluminium^
- Recycling of e-waste – treatment and processing

- Methane capture at landfills

- Plug-in hybrid vehicle technology
- Hydrogen fuel cell vehicles

- Smart meters
- HVAC systems
- Solar thermal cooling^

- Household biogas digesters^
- Solar cookers^
- Ethanol cookstoves
- GM crops – genetic eng. for fuel prod. and carbon seq.
- Genome editing – CRISPR/Cas to enhance resilience of food crops to changing climate
- Precision agriculture

- Carbon capture, utilisation and storage

Medium (30-70%)

- Wind turbines – towers
- Solar PV – crystalline cells and modules
- Solar water heaters
- Hydropower – micro hydroelectric systems
- Geothermal energy – power plants
- Smart mini-grids – community based for rural areas
- Bioenergy – 2nd and 3rd generation biofuels

- Rainwater harvesting

- Composting

- Energy efficient lighting – LED lamp production
- Solar electric cooling

- Solar water pumps
- Bioremediation (soil and water)

High (>70%)

- Hydropower – large systems with dams
- Bioenergy – 1st generation biofuels

- Wastewater treatment – municipal sewage treatment
- Water metering – mechanical

- Recycling of e-waste – mechanical separation

- Energy efficient lighting – solar lanterns

- No-till cropping and agroforestry to prevent soil erosion

Note: (^) denotes low to medium level
Source: Authors

Battery energy storage might grow moderately to rapidly even if currently costs are high (mostly driven by large-scale renewable energy projects). The sophistication of this technology is very high so developing countries will see low value added and few technological capabilities provided locally (less than 30 per cent) (see Figure 12). Yet, these technologies are also extremely relevant for remote areas in developing countries so cost reductions can contribute significantly to technology diffusion.

Rainwater harvesting is likely to see rapid market expansion in developing countries given the expected increase in water shortages for agriculture, business and household use. This technology is readily available, complements a wide range of applications and is less sophisticated. The Delphi experts argue that adaptive innovations are needed and foreseeable.

Rapid market development in the recycling sector is expected for paper, glass and aluminium, while other types of recycling (i.e., e-waste) are expected to grow at a relatively slower pace (see Figure 11). Recycling systems should become more systematic and formalised in the coming years. Growth in this market is likely to be constrained by the institutional framework and the large informal sector. Domestic value creation and technological capabilities are expected to remain low in this sector (see Figure 12), as technology imports are considered easy and less costly.

Efficient lighting technologies, solar cooling and smart power grids are expected to deploy rapidly in developing countries, with moderate to high domestic value-added and technological capabilities (except for solar thermal cooling, where only low value-added is expected locally) (see Figure 11 and 12). Energy efficient lighting technologies are well-proven technologies but depend on system innovations and smart systemic solutions.[21] Low wages and good technical skills might help developing countries to increase domestic value creation, but a lack of competency in manufacturing more sophisticated products and systems might limit what they can offer locally. Smart mini-grids are also relatively accessible to developing countries in terms of technological capabilities.

In the transportation sector, BRT systems are seen to be promising markets in developing countries (they show moderate to rapid market development, see Figure 11), but growth may be constrained mainly due to poor governance

21 Currently, each piece of an LED fixture requires different levels of know-how to produce and varies in degree of sophistication.

and planning capabilities as well as vested interests from incumbents in the sector.

Most green technologies are likely to see only moderate market development in developing countries by 2030. Nevertheless, policy makers should pay particular attention to these technology sectors as in the long-term improvements in market conditions and capabilities will favour some of them, like wind energy, SWH, hydropower, biomass, wastewater treatment, water metering, inter-modal transportation, a number of energy efficient technologies in buildings, agriculture-related technologies, environmental analytics and monitoring tools, carbon footprinting and energy efficiency in industrial processes.

As discussed earlier, wind energy is a relatively sophisticated technology. Despite the significant cost digressions, financing costs remain high for developing countries. Therefore, small-scale wind power plants are likely to see more rapid market developments in these economies. For these reasons, domestic value creation and technological capabilities are likely to remain low (mainly limited to steel structures) and the value chain will continue to be dominated by multinational companies.

SWHs will also see moderate deployment, but markets will depend on existing promotion and incentives schemes. Given lower technological sophistication and lower costs, developing countries are expected to provide up to 70 per cent of value added and technological capabilities domestically. Critical here is quality assurance, which will determine the extent to which markets develop.

Bioenergy will also see moderate market development by 2030 and moderate value added domestically. The Delphi experts point to several challenges related to this green technology family: the need for public support and investment and the relatively high technological sophistication for developing countries.

The water management sector is also increasingly important for these countries. Wastewater treatment and water metering technologies are believed to see moderate (or low to moderate) levels of market growth by 2030. Increasing prices for fresh water (driven by rising water scarcity and corrective policies) will increase demand for wastewater treatment solutions. Experts claim that developing countries will provide high domestic value added and technological capabilities (except for non-mechanical and electromechanical water metering technologies where local value added is expected to be less than 30 per cent) (see Figure 11 and Figure 12); moreover, this sector could see important frugal innovations (and technology adaptation) in the coming decade.

A number of other green technologies are also expected to see moderate market development, such as some technologies in the energy efficiency in buildings family and related to the agriculture sector. Here too, expected domestic value added and technological capabilities are low to medium at best.

Slow market development is likely to be seen for several green technologies for which costs and technological complexity remain high and/or the regulatory framework (e.g., incentives and enforcement mechanisms) remains weak, such as CSP, wastewater treatment, grey-water reuse, recycling of e-waste, anaerobic digestion and methane capture at landfills, electric and plug-in vehicles as well as hydrogen fuel cell vehicles, solar cookers, organic agriculture, genome editing, and carbon capture and storage (see Figure 11). As Figure 12 illustrates, for most of these technologies developing countries are also expected to provide little domestic value added and technological capabilities.

In the e-waste recycling sector, for example, legislation is being developed in a number of countries, but political blockages are strong, and a lack of awareness prevents deployment. Most recycling markets in developing countries are competing with established informal sectors, which are difficult to transform into formal and modern recycling systems. Yet, the generation of e-waste is expected to rise in the coming years. Financing is also necessary to treat all e-waste fractions (including the hazardous and costly ones), which might have to come from taxes, eco-levies or extended producer responsibility legislation. Thus, legislation and its enforcement are crucial. While waste collection and partial reuse are expected to happen domestically, technological capabilities are expected to remain low in the coming decades (especially in treatment and processing, while mechanical separation is likely to see higher domestic value added, as per Figure 12).

Electric and plug-in vehicles are also expected to see slow market development, especially due to their limited affordability, the lack of stringent emissions standards, lack of car manufacturing facilities and substantial fossil-fuel subsidies. Some frugal innovations might emerge in this sector and e-bikes might diffuse more widely, but in general, local value added is expected to stay low in the coming decades.

Markets for organic agriculture are also expected to be restricted by low purchasing power, weak policy frameworks and a lack of efficient quality assurance systems, such as certifications. As long as the middle class in developing countries grows slowly, diffusion of these technologies is expected to be limited and organic agriculture will be limited to subsistence farming.

Box 1: Insights into other aspects of the transition to a green economy

Round 2 of the green technology Delphi survey aimed to both (a) validate the main trends identified by experts in the first survey round and (b) examine in greater detail some aspects that appeared surprising or unclear in the results of the first survey.

For instance, despite its potential and promising forecast in global technology surveys (e.g., International Energy Agency (IEA)), our experts predict that carbon capture and storage will only diffuse slowly between now and 2030. We learned from the second survey that several factors contribute to this expected trend: high costs and upfront investment, a lack of regulation, high technology complexity and lack of knowledge, political resistance to "risky" technologies, as well as its low economic development potential.

We also wanted to know why wastewater treatment technologies are expected to diffuse only slowly in developing countries, although value added and domestic capabilities are seen to be high. Aside from high capital costs and upfront investment, limited knowledge on appropriate technologies, limited regulation of water quality and weak conformity assessment in implementation are factors explaining this trend. Additionally, a lack of awareness and sense of urgency, along with poor infrastructure planning, are expected to slow down the rate of diffusion for this set of technologies. To address these barriers, education, awareness raising, capacity building, investments for cost reduction, quality improvements, stricter regulations and financing are needed. Also, strengthening the role of local government and promoting smaller-scale technologies are believed to play a role.

Box 1 (cont.): Insights into other aspects of the transition to a green economy
By contrast, the recycling sector is expected to develop rapidly in developing countries, but only limited value added and domestic capabilities are expected to be created by 2030. Insufficient incentives and investment in recovery have been mentioned as explanations for this outcome. Moreover, most recycling plants tend to be foreign owned and the original equipment manufacturers (OEMs) are not required to collect and reuse materials. We also learned that value added and capabilities could be further increased and accelerated in several activities, such as the separation of complex wastes, domestic and industrial waste, urban mining, demand reduction for primary resources, new methods of recycling, de-manufacturing of goods, and adaptation of systems and technologies. To this end, more investment in R&D is needed, as is knowledge transfer, training, building system capabilities, regulations, and technological capabilities for SMEs. Similar trends are also seen for technologies related to energy efficiency in buildings (i.e., high rates of diffusion but low value added and capabilities). Here, lack of domestic standards, low capabilities for implementation, and a stronger focus on procurement costs rather than on maintenance, are factors that explain this trend. More learning could be done in several activities and technologies related to passive housing, solar cooling, insulation materials, standards and certification, water and heating systems, but also in credit lines and financing tools for retrofitting old infrastructure. To support these processes, R&D cooperation, development of suitable business models, incentives for reducing energy consumption, efforts to connect standardisation with sustainable public procurement, adaptation of technologies to local conditions, and of course, regulation and education and training are seen as necessary interventions.

4.3 Summary on future market trends and domestic capabilities

As our findings illustrate, future market trends critically depend not only on supportive regulations for technology deployment, but also on the degree of sophistication of the related technologies and the extent of domestic technological capabilities. Specifically, sophisticated technologies, such as wind battery energy storage, GM crops and 2nd and 3rd generation of biofuels, are expected to diffuse and localise slowly in countries with low technological capabilities. By contrast, technologies with low level of sophistication, such as SWHs, ethanol cookstoves and wastewater treatment, are expected to see faster market development and localisation even in countries with lower technological capabilities.

Along these lines, our Delphi study findings allow us to highlight different trends for emerging and developing countries for the coming decade.

Emerging economies are likely to see moderate to rapid market development in most green technology sectors (such as electricity generation, waste management, transportation and energy efficiency in buildings). China and India stand out regarding expectations for market development, while in other emerging economies the direction is less clear. Respondents suggest that Mexico, for example, is likely to see fast rates of deployment for wind and solar energy technologies. This would not be the case in Russia, mostly due to inadequate policy framework conditions.

Despite these expected fast deployment rates, most technologies are going to see up to 70 per cent of value added and technological capabilities being provided locally, except for some of the green technologies with a low level of sophistication, such as wind towers and wastewater treatment, for example. Even in the fast-growing emerging economies, little value added (<30 per cent) is expected for technologies with a high degree of sophistication, such as concentrated solar power (CSP), battery energy storage and plug-in and fuel cell vehicles. For these technologies, most innovation will come from developed countries.

Developing countries, by contrast, are likely to see rapid market development only in selected technologies, such as solar PV energy, recycling of paper, glass and aluminium, energy efficient lighting and drought resistant crops. Markets for most green technologies are expected to develop only slowly to moderately. Reasons behind these different expectations relate to, among other things, less ambitious and consistent policies, lower financing and FDI, and weaker implementation and maintenance capabilities.

These trends also reflect future implications for domestic value addition and technological capabilities. Particularly, for most green technologies, less than 30 per cent domestic value added is expected in developing countries and for some more mature technologies with a medium degree of sophistication, this share may reach 70 per cent (for instance, for wind towers, crystalline cells and modules, micro-hydropower systems and solar mini-grids).

Our findings on expectations regarding market development and localisation of value added and capabilities for various green technologies informed the next important question of our study, specifically what do these trends mean for the investments required to build up QI capabilities. We discuss these findings in the coming section.

4.4 Implications for QI investments

The future development of green technology sectors (in terms of deployment of technology, use, manufacturing and integration in global value chains) critically depends on a functioning QI system. Thus, the Delphi II survey was aimed at understanding the implications of these trends on the interrelated QI system comprising standards development, metrology, accreditation and conformity assessment (testing, inspection, product and system certification, and calibration). For this Delphi survey, 185 international experts were invited to provide their expertise. A total of 34 experts contributed their insights (a response rate of 18.4 per cent) and provided information and explanations that enriched our results. The relatively low response rate can be explained by the specifics of the QI field: while few experts have broad expertise on a range of technologies, the majority have very deep technical expertise in a very specific technology (or family of technologies).

We explored four main issues in this Delphi survey:

- We asked experts to assess the required level of sophistication (low to high) of the QI system (for the green technology families explored in the first two Delphi surveys) if most components are being imported, which is the case in most developing countries.
- For a pre-selected list of green technologies (that are expected to become particularly relevant for developing and emerging economies by 2030) we asked experts to
    - Identify the QI areas in which new technological developments or new market demands call for major investments in QI-related technical infrastructure and/or institutional capabilities and
    - Specify which kinds of QI system improvements are relevant.
- We asked experts to assess expected trends in environmental regulations, (mandatory) standards and private environmental standards.
- Lastly, we inquired about whether NQI bodies tend to increasingly develop voluntary sustainability standards (VSS) and carry out conformity assessment activities on the basis of these VSS.

Below, we systematically discuss the findings on these key questions.

4.4.1 Sophistication of the QI system

Understanding the level of QI system sophistication enables experts working in this field to assess the challenges associated with implementing and/or strengthening QI for specific technology areas. The term “sophistication” is of course subjective (as in our earlier assessment of different technologies) as the reality shows a continuum of QI complexity and variation across its various dimensions. For example, for a specific green technology, standards and technical regulations may be quite well developed and accessible but conformity assessment may be challenging to implement. Nevertheless, our general assessment aims to highlight technology areas that require more effort to set up effective QI systems.

Table 13 links the degree of QI sophistication of technologies with their sophistication level, as assessed earlier. This grouping of green technologies suggests that QI interventions to support dissemination should be relatively easy for those technologies with a low level of technology sophistication and a low or medium level of QI sophistication (e.g., solar water heaters, the towers for wind turbines, first generation bioenergy technologies, hydropower and recycling of paper, glass and aluminium). The complexity of QI interventions is expected to gradually increase for technologies with a medium level of technological complexity. As such, technologies that are both highly complex and very demanding in terms of QI are expected to see low levels of diffusion. If markets are to grow for these technologies, the expectation is that most of these technologies (e.g., the blades and generators of wind turbines, thin-film and organic solar PV, plug-in hybrid vehicles, and carbon capture and storage) would be imported rather than manufactured partially or fully domestically, and a large share of QI services may be outsourced rather than supplied locally, especially where domestic technological capabilities are weak. Thus, it is the types of technologies listed in the grey area of Table 13 that pose the most challenges in terms of building up domestic capabilities, despite the potential benefits they may offer with respect to spillover and learning effects.

Table 13: Levels of technology sophistication and QI for various green technologies

Technology sophistication	QI sophistication		
	High	**Medium**	**Low**
High	• Wind turbines – blades and generator • Solar PV – thin-film and organic • Battery energy storage • Bioenergy – 2nd and 3rd generation • Smart power grids* • Gasification or combustion of municipal waste • Plug-in hybrid vehicle technology • Hybrid fuel cell vehicles • GM crops • Genome editing • Carbon capture and storage	• Energy efficiency in transportation • Electric engines and simple electric cars • Energy efficient lighting	N/A
Medium	• Concentrated solar power • Solar PV – crystalline cells and modules • Co-generation	• Desalination • Water metering	• Hydropower • Recycling of paper, glass, aluminium

Table 13 (cont.): Levels of technology sophistication and QI for various green technologies

Medium	• Composting* • Intermodal transportation systems • Organic agriculture • Carbon footprinting tools	• Recycling of electronic and electrical equipment waste • Recycling of building materials^ • Anaerobic digesters* • Methane capture at landfills • Advanced hydrocarbon fuels • Smart meters • Thermal insulation • HVAC systems • Solar cooling • Soil and water remediation • Environmental analytics and monitoring tools • Energy efficiency in industrial processes	• Household biogas digesters • Precision agriculture (sensor technologies)
Low	• Geothermal energy	• Wastewater treatment • Grey-water reuse • BRT systems • Ethanol cookstoves • Higher yielding seeds • Solar water pumps^	• Wind turbines – towers • Solar water heaters • Bioenergy – 1st generation • Rainwater harvesting • Solar cookers

Note: (^) denotes low to medium QI sophistication, (*) denotes medium to high QI sophistication
Source: Authors

Having mapped the sophistication and complexity of various technologies and their associated QI system, the following questions arise. Given expected trends in market development for various green technologies, how "challenging" would it be to support this process as reflected by the sophistication of the QI system for the respective technology? Which technologies would require more effort (from national and international stakeholders) to set up the needed NQI system to enable markets to grow to their potential?

As we saw in Chapter 3, the expected speed of market development varies significantly between emerging and developing countries. Table 14 and Table 15 map those findings to the sophistication of the QI system for the respective technologies. Again, as QI services for technologies with a low level of QI sophistication are assumed to be relatively easy to set up and transfer, it is the technologies with a medium and high level of QI sophistication that require most effort from (national and international) QI stakeholders. While it is relatively easy to adopt international standards even with regard to highly sophisticated technologies, conformity assessment, which goes beyond inspection services, is a difficult issue. Green technologies may be a complex bundle of technologies and thus require several testing runs. In the case of a solar home system (SHS) a renewable energy source (solar PV), an energy storage device (battery), and one or several light sources and various enclosures and additional components (e.g., wiring, cables, switches) are needed. Testing all these elements separately as well as testing their interoperability requires expensive testing equipment, well-trained experts and reference materials. Testing larger-scale and more complex technologies (e.g., CSP, smart power grids) raises additional challenges and costs. Under conditions of limited financial budgets these investments might only be justifiable when a sufficient and lasting demand can be expected. Until then, local actors might have to rely on conformity assessment certificates extended by internationally accredited conformity assessment bodies.

Focus should be placed on technologies that are expected to diffuse rapidly and moderately instead of on those for which markets are expected to be slow to develop. Both of these conditions call attention to the technologies listed in the grey area of Tables 14 and 15.

Table 14: Speed of market development in emerging economies and the sophistication of QI for selected green technologies

Market development	QI sophistication		
	High	**Medium**	**Low**
Rapid	• Concentrated solar power • Battery energy storage • Smart power grids • Hydrogen fuel cell vehicles • GM crops*	• Wind energy • Solar PV • Co-generation • BRT • Inter-modal transportation • Electric and plug-in vehicles • Thermal insulation • Energy efficient lighting • HVAC systems • Solar cooling	• SWH • Recycling of paper, glass, aluminium • Drought resistant crops
Moderate	• Geothermal • Gasification or combustion of municipal waste • Genome editing (CRISPR/Cas) • Carbon footprinting tools*	• Hydropower • Bioenergy • Desalination • Wastewater treatment • Water metering* • Grey-water reuse systems • Recycling of electronic and electrical equipment* waste • Recycling of building materials	• Rainwater harvesting • Composting • Household biogas digesters • Solar cookers • Solar water pumps

Table 14 (cont.): Speed of market development in emerging economies and the sophistication of QI for selected green technologies

Moderate		• Anaerobic digesters • Energy efficiency in transportation • Smart meters • Organic agriculture • Higher yield seeds (for arid and saline soils) • Soil and water remediation* • Sensor technology • Ethanol cookstoves • Environmental analytics and monitoring tools • Energy efficiency in industrial processes	
Slow	• Carbon capture and storage^	• Methane capture at landfills • Hydrogen fuel cell technology • Advanced hydrocarbon fuels	N/A

Note: (^) denotes slow to moderate market development, (*) denotes moderate to rapid market development; *italics* indicate an assumption has been made regarding the speed of market development because no answers were given the technology survey
Source: Authors

Specifically, as most green technologies are expected to diffuse moderately to rapidly in emerging economies, the relevant technologies for building up and strengthening QI systems extensively cover most technology families (see Table 14). The need for QI interventions is considered less urgent for technologies that are expected to diffuse rapidly but have a low QI sophistication level (e.g., solar water heaters and recycling of paper, glass, aluminium) and those that are expected to diffuse slowly (e.g., carbon capture and storage, methane capture at landfills).

For developing countries, the constellation of technologies based on these criteria looks quite different (see Table 15). First, a much larger and diverse set of technologies are expected to only diffuse slowly in the coming decade, as seen also in Chapter 3 (across a wide range of sectors from energy to waste, transportation, and agriculture). This reduces the focus to a more constricted number of technologies that are to diffuse moderately to rapidly and at the same time have a medium to high level of QI sophistication. Green technologies associated with, for instance, energy generation (e.g., solar and wind, hydropower, storage), energy efficiency technologies (e.g., lighting, HVAC, solar cooling), transportation (e.g., BRT, inter-modal transportation), and waste management, would require support to build up required QI capabilities to enable market development. As developing countries may have much lower technological capabilities (also QI related) than emerging economies, we argue that QI related interventions and investments should not only focus on those green technologies that are to diffuse rapidly/or moderately and have medium to high QI sophistication. Rather, low QI sophisticated technologies should also be in focus, such as recycling of paper, glass, aluminium, SWH, water metering, and solar water pumps. Short-term interventions to strengthen domestic QI in these sectors may have powerful effects on enabling markets to develop to their full potential.

Table 15: Speed of market development in developing countries and the sophistication of QI for selected green technologies

Market development	**QI sophistication**		
	High	**Medium**	**Low**
Rapid	• Smart power grids^	• Solar PV • Co-generation • Energy efficient lighting • Solar cooling	• Rainwater harvesting • Recycling of paper, glass, aluminium • Drought resistant crops and cultivation practices
Moderate	• Geothermal • Battery energy storage • Gasification or combustion of municipal solid waste • GM crops • Genome editing (CRISPR/Cas)	• Wind energy • Hydropower • Bioenergy • Desalination • Recycling of building materials • BRT* • Inter-modal transportation • Energy efficiency in transportation • Advanced hydrocarbon fuels • Thermal insulation • Smart meters • HVAC systems* • Ethanol cookstoves	• SWH • Water metering • Composting* • Household biogas digesters • Solar water pumps

Table 15 (cont.): Speed of market development in developing countries and the sophistication of QI for selected green technologies

Moderate		• Soil and water remediation • Sensor technology • Environmental analytics and monitoring tools • Carbon footprinting^ • Energy efficiency in industrial processes	
Slow	• Concentrated solar power • Carbon capture and storage	• Wastewater treatment^ • Grey-water reuse systems^ • Recycling of electronic and electrical equipment waste^ • Anaerobic digesters • Methane capture at landfills • Electric and plug-in vehicles^ • Hydrogen fuel cell technology • Organic agriculture • Higher yield seeds (for arid and saline soils)	• Solar cookers

Note: (^) denotes slow to moderate market development, (*) denotes moderate to rapid market development; *italics* indicate an assumption has been made regarding the speed of market development because no answers were given the technology survey
Source: Authors

4.4.2 Needed QI system improvements

To get to a more granular level of understanding of the implications of a green economy transition on the QI, we further used the Delphi survey to examine in greater detail in which part of the NQI system most improvements are necessary by 2030, driven either by new technological developments or new market demands. The specific questions we asked were

- In which parts of the QI system do you see the most need for improvement by 2030 considering a country that mainly imports each technology (or that mainly develops each technology locally)?
  - Standards – development, adoption, use
  - Technical regulation – enforcement, market surveillance
  - Conformity assessment – testing, inspection, certification
  - Metrology – calibration, verification, research
  - Accreditation
- Explain why and what kind of improvements you consider necessary and provide examples.

As also discussed in Chapter 2, the QI system and its interrelationships are highly complex. To reduce complexity and be able to explore in more detail the areas that would need further QI improvements we narrowed down the green technology families to (a) a selection of those predicted to experience fast growth in the coming decade and (b) those which PTB staff consider less understood (internally) in terms of QI system needs. This smaller group of technology families includes wind energy, concentrated solar power, battery energy storage, solid waste management and recycling, energy efficiency in buildings, smart grids and agriculture-related green technology.[22] QI experts who participated in the Delphi survey also mentioned the relevance of other green technologies, such as energy efficiency in production and solar PV, which we included in our results.

Our results show that, not surprisingly, for all technologies, improvements are needed across all QI system components, but to different degrees depending on the sophistication of technology and its maturity. We have compiled the

22 These technologies were pre-selected following discussions with PTB and DIE staff during a workshop in August 2018.

results in Tables 16 and 17 by ordering the QI system components by the number of responses indicating it is in need of improvement. We can consider this ranking a prioritisation of interventions to improve the NQI systems.

Several aspects stand out in these figures, which are in line with what we would expect. First, there is a difference between the NQI system components that need major investments depending on whether a country imports or manufactures the technology locally. Second, experts consider accreditation to be a relatively lower priority area when considering interventions to strengthen the QI for specific green technology families. As we saw in Chapter 3, technology sophistication varies within the same family of green technologies or for different parts and components, which would also create variation in QI sophistication levels. Wind energy and solar PVs are two such examples. Thus, we are aware of the generalisation we make by treating wind energy, for instance, as one entity when discussing the need for QI interventions.

Even then, however, Table 16 suggests that for countries that mainly import the respective technology, QI improvements are necessary across the entire system (except for accreditation) for technologies such as wind energy, concentrated solar power, battery energy storage, and energy efficiency in buildings (in which case metrology has been considered highly important but by a smaller number of experts).[23] QI experts argued that, in the case of wind energy it is necessary, for example, to periodically recalibrate wind towers, measure capacities to determine wind velocity and ensure grid stability and power quality, as well as regulate the type and quality of equipment that should be imported and used. In the case of concentrated solar power technology, it has been claimed that standards already exist and are important, but laboratories for conformity assessment with adequate testing equipment are essential for improving the usage of this technology. In the case of battery energy storage, technology issues of safety and end-of-life disposal requirements have been mentioned. In the case of energy efficiency in buildings, experts considered standards and technical regulations to be key to enabling the large potential of these technologies in developing countries. Standardisation of materials has been mentioned as fundamental to guaranteeing an adequate quality of imported products. These QI elements need to be coupled with testing and certification schemes to ensure quality and orientation to investors, construction companies and buyers.

23 These are also technologies deemed to have a high level of technological sophistication (and medium to high level of QI system sophistication).

Table 16: "Prioritisation" of improvement needs in the NQI system for a country that mainly imports the technology (number of responses)

	Standards	Technical regulation	Conformity assessment	Metrology	Accreditation
Wind energy	11	12	11	12	4
Concentrated solar power	8	6	8	6	4
Solar PV	2	2	4	3	1
Battery energy storage	8	9	8	7	4
Solid waste management	6	11	5	3	4
Energy efficiency in buildings	9	9	9	3	4
Smart grids	6	5	6	7	3
Agriculture	2	2	9	2	3
Energy efficiency in production	2	2	4	2	-

Note: Numbers represent the total responses indicating the respective QI element is most in need of improvement
Source: Authors

Table 17: "Prioritisation" of improvement needs in the NQI system for a country that develops most technology components locally (number of responses)

	Standards	Technical regulation	Conformity assessment	Metrology	Accreditation
Wind energy	10	8	14	14	8
Concentrated solar power	9	7	11	9	7
Solar PV	4	2	5	5	2
Battery energy storage	8	8	10	8	8
Solid waste management	6	7	6	4	2
Energy efficiency in buildings	8	5	10	7	5
Smart grids	8	5	8	7	4
Agriculture	8	7	10	7	6
Energy efficiency in production	4	2	5	5	2

Note: Numbers represent the total responses indicating the respective QI element is most in need of improvement.
Source: Authors

The relative importance of different QI elements is considered slightly different for the case when most of these technologies (or parts and components) are manufactured locally (see Table 17). Conformity assessment and metrology become relatively more important for most green technology families. The development, adoption and use of standards are considered highly important across the board. In the case of wind energy, measurement capacities are again considered highly important, along with component testing and metrology of large torques for various components. Supporting local manufacturing with testing laboratories is expected to foster innovation. In the case of energy efficiency in buildings, the aspects seen as important are similar to those in which most technologies are imported. In addition, however, a wide range of local testing capacities are considered essential to facilitate product development. Smart grids are expected to become increasingly important due to trends towards decentralised energy systems. Experts argue that this trend implies growing demand for QI in all areas, particularly standards, testing and calibration, related to, for instance, ensuring quality of electric energy supply, stability of frequencies, efficiency of transmission methods and metering devices for consumers.

Box 2: Trends in environmental regulations and standards
We have also asked experts to assess (for the country or countries they are familiar with) whether they think environmental regulation and (mandatory) standards are increasingly strict (demanding). Most agreed this is the case (e.g., in most of North America, South America, North Africa, India and Ghana). Exceptions were countries such as Egypt, Myanmar, Senegal, Ethiopia, Costa Rica and West Africa. Across the board, however, experts agreed that international commitments regarding climate change, peer pressure and access to export markets contribute to improving the regulatory framework. One concern, however, is that even if regulations exist in many locations, they are often unclear or inadequate, and implementation is hardly effective. In the Latin American context, while environmental regulations are increasingly present, few countries manage to convert green issues into competitive advantages. As we will see in Chapter 5, this challenge is also reflected in more detail in the country case studies.

Box 2 (cont.): Trends in environmental regulations and standards
A second question we asked was whether environmental regulations and (mandatory) standards are more effectively enforced.[24],[25] Here most experts argue that this is not the case in most of Latin American, Egypt, West Africa, Nepal and Myanmar. Enforcement seems to be relatively effective in countries such as Ghana, Ethiopia, Indonesia, India, Morocco, Algeria, Pakistan, Bangladesh, Peru and Sri Lanka. We also wanted to know whether market trends and private environmental standards put increasing compliance pressure on local companies. Most experts agreed that they do, especially in the context of Latin American countries, India, Indonesia, Myanmar, Bangladesh, Ghana and Ethiopia. But this is not always the case in Maghreb countries, Brazil, West Africa and some countries in Latin America (such as Brazil and Mexico). The main argument here is that private environmental standards are important only for niche markets that are export oriented. Where consumer awareness has improved (as in the case of Bangladesh, for example) local companies feel pressure to align their activities to international standards. Alternatively, low prices remain the single most important criteria in consumption choices in developing countries. The last question in our survey aimed to understand whether VSS (which have gained prominence in the past decade) are increasingly developed by recognised NQI bodies and whether such stakeholders carry out conformity assessment activities on the basis of such standards. Most experts argued that this is not the case in their countries of expertise, even if they think VSS will play an important role in the future. One reason for this gap is NQI bodies' lack of capability to engage with this issue, since VSS are developed outside the ISO community, as their development requires more than a simple replication or expansion of "Western" systems to other countries.

24 Environmental regulation is issued by the government and refers to laws aimed at protecting the environment and controlling the way that individuals and firms operate with respect to the environmental effects of their actions.

25 "The use of standards may be voluntary, or they may be referenced in regulation (therefore mandatory)" (ISO, n.d.).

4.5 Summary on QI implications

Different trends in market development and domestic technological capabilities have distinct implications for the needed QI capabilities for the specific green technologies. First, as our findings show, most green technologies with a medium to high degree of sophistication (of related technologies) also require a highly sophisticated QI system. Thus, where markets are expected to grow faster for such technologies (i.e., emerging countries), QI capabilities need to be upscaled and upgraded. Examples of such technologies are energy storage in batteries, thin-film and organic solar PV technologies, electric engines and simple electric cars, plug-in hybrid and fuel cell vehicles, desalination, recycling of e-waste and building materials, and a range of technologies related to energy efficiency in buildings, to just name a few.

In emerging economies, as most green technologies are expected to diffuse moderately to rapidly, most interventions for building up and strengthening QI systems extensively cover most technology families. Yet, as emerging countries have higher technological capabilities and more established NQI systems, international cooperation in the QI space should focus especially on improving the effectiveness of existing QI services and institutions. For this reason, in the case of technologies that are predicted to diffuse moderately to rapidly but have a low QI sophistication level (such as SWHs, recycling of paper, glass, aluminium, and household biogas digesters, composting and solar cookers) QI interventions are considered less necessary.

For developing countries, the constellation of technologies requiring QI interventions based on these criteria looks quite different. First, a larger number of green technologies is expected to diffuse only slowly in the coming decade. Second, the QI sophistication of these technologies varies significantly across technologies with potential for market development. Third, developing countries have much lower technological capabilities (including QI-related capabilities) than emerging economies. For these reasons, international cooperation to build up the necessary NQI system must be much wider ranging. Green technologies associated with, for instance, energy generation (e.g., solar and wind, hydropower, storage), energy efficiency technologies (e.g., lighting, HVAC, solar cooling), transportation (e.g., BRT, inter-modal transportation), and waste management, would require support to build up required QI capabilities to enable market development. Therefore, our findings suggest that QI-related interventions and investments should not only focus on those green technologies that are to diffuse rapidly and moderately and have medium to high QI sophistication. Rather, technologies with low QI sophistication should also be in focus, such as recycling of paper, glass, aluminium, and SWHs, water metering, and solar water pumps. Short-term interventions to strengthen domestic QI in these sectors may have powerful effects on enabling markets to develop at full potential.

As introduced in Section 4.2.2, for a select group of green technologies (i.e., wind energy, CSP, battery energy storage, solid waste management, energy efficiency in buildings, smart grids and agriculture-related green technologies) we also examined which QI elements (i.e., standards, technical regulation, conformity assessment, metrology or accreditation) are considered in need of improvement. We found that, not surprisingly, those green technologies require interventions in all QI system components, but to different degrees depending on the sophistication of technology and its maturity. At the beginning of this study, we hypothesised that these interventions would differ if the country mainly imports the green technology (which is the case for most developing countries) or if the country develops most technology components locally (which is increasingly the case for emerging economies, at least for some green technologies).

What we found is that for countries that mostly rely on imports of green technologies, improvements are necessary across the entire NQI system (but less so for accreditation). This is the case for technologies such as wind energy, concentrated solar power, battery energy storage, smart grids and energy efficiency in buildings.[26] For the latter, metrology has been considered highly important, but by a smaller number of experts. In the case of solid waste management many more experts considered technical regulation to be an area in need of QI interventions, while in the agricultural sector this was the case for technical regulation and conformity assessment.

More specifically, for the case of wind energy several QI interventions were indicated as important, including the periodic recalibration of wind towers, measurement capacities to determine wind velocity and ensure grid stability and power quality, as well as regulations for the type and quality of equipment being imported. For the case of CSP, it has been claimed that standards already exist and are important. Laboratories for conformity assessment

26 Not surprisingly, these are also technologies deemed to have a high level of technological sophistication (and a medium to high level of QI system sophistication).

with adequate testing equipment are essential for improving the usage of this technology but are often lacking. In the case of battery energy storage, standards and regulation for safety and end-of-life disposal requirements are needed. Standards and technical regulation have also been mentioned in the case of energy efficiency in buildings, they are needed to enable the large potential of these technologies in developing countries. These QI elements need to be coupled with testing and certification schemes to ensure quality of materials and orientation to investors, construction companies and buyers.

When most of these green technologies (or parts and components) are manufactured locally, the relative importance of interventions in the QI system is considered slightly different. Conformity assessment and metrology are given more importance for most green technology families. The development, adoption and use of standards are considered highly important across the board. In the case of wind energy, measurement capacities are considered highly important again, along with component testing and metrology of large torques for various components. Supporting local manufacturing with testing laboratories is considered to contribute to and foster innovation. When it comes to energy efficiency in buildings, the aspects considered important are similar to the requirements when most technologies are imported. However, in addition, a wide range of local testing capacities is considered essential for this technology to facilitate product development. As smart grids are predicted to become increasingly important due to trends towards decentralised energy systems, a growing demand for QI can be expected in all areas, particularly standards, testing, and calibration, related to, for instance, ensuring quality of electric energy supply, stability of frequencies, efficiency of transmission methods and metering devices for consumers.

5 Case studies of transition to a green economy and implications for QI

The results from the Delphi surveys, discussed in the previous chapter, point to important differences between developing and emerging countries in terms of expected trends in the transition to a green economy, calling for different policy interventions. Emerging economies are likely to see moderate to rapid market development for most green technologies. For a large group of green technologies, emerging economies are also expected to acquire high value-added and technological capabilities (through, for instance, local manufacturing and innovation). This is not the case in developing countries, where markets for most green technologies are likely to develop only slowly to moderately. Value added and technological capabilities are also expected to remain low in the next decade. These differences are reflected in the needed investments in QI-related technical infrastructure and/or institutional capabilities by 2030 to support the transition to a green economy.

In this chapter, we delve deeper into a few country case studies to gain a better understanding of the specific challenges and opportunities associated with such a transition and the QI implications. The case studies (selected in consultation with PTB) represent countries at different levels of development, with different market sizes and in different world regions. These countries are also important partner countries in PTB's international cooperation programmes. In-depth case studies were performed in 2018 and 2019 in India, Morocco and Ethiopia (for a period of two weeks each).

For feasibility purposes, we narrowed the technological focus to not more than five green technology sectors in each country. The selected green technology sectors had to fulfil two sets of criteria. From a more global point of view, the sectors needed to contribute to major environmental improvements, have a potentially large impact on socioeconomic development, and require or depend on an appropriate QI system. As this first set of criteria is true for a large number of green technologies, we additionally used the following set of more specific criteria.

- We pre-selected three green technology areas to be examined in more than one country for comparative purposes: renewable energy systems, energy efficiency in buildings and solid waste management. These technologies are both relatively mature and highly important for developing countries given increasing urbanisation rates and the need to reduce energy demand.
- To identify the most relevant green technology sectors we examined in detail for each country their national priorities as reflected in the nationally determined contributions (NDCs) and the various development strategies.
- Finally, we also considered including green technology sectors that are not currently present in the project portfolio of PTB but may be of interest in the near future.

Table 18 illustrates the resulting selection of sectors for the country case studies. In-depth, semi-structured interviews were conducted (35 interviews in India, 19 in Morocco and 19 in Ethiopia) with a diverse set of stakeholders (policy makers, green economy analysts, academics, researchers and QI professionals) (see Table A3 in the Appendix). Moreover, during or at the end of the fieldwork, workshops were organised with local stakeholders to triangulate, discuss and refine the findings with a diverse expert group.

Table 18: Sectors examined in the three country case studies

	India[27]	Morocco	Ethiopia
Renewable energy systems		X	X
Energy efficiency in buildings	X	X	
Solid waste management	X	X	X
Sustainable transportation	X	X	X
Water management		X	
Air pollution	X		
Sustainable agriculture			X

Source: Authors

Below, we examine these country case studies in more detail. A more extensive discussion of each of these case studies can be found in the respective fieldwork reports (Stamm, 2020; Vidican Auktor, 2019a, 2019b). For each of the case studies, we start with an overall discussion of national priorities related to the transition to a green economy. We then analyse the NQI system, followed by an assessment of specific developments in the selected green technology sectors and needed QI interventions.

5.1 India

India is one of the fastest growing emerging economies in the world, home to 17 per cent of the world's population. In the next decades India is expected

27 In India, we also explored smart grids, but to a lesser degree due to time constraints. A short overview of key challenges related to this technology in India has been provided in the fieldwork report (see Vidican Auktor, 2019a). Renewable energy, while highly important and well developed in India, has been left out of this case study as extensive literature exists and work is already being done in the QI area.

to become the world's most populous country (Juyal et al., 2018). Rapid urbanisation rates,[28] increased income levels[29] and changes in consumption patterns will generate the need to reconcile energy demand with climate change and environmental degradation even further. As a result (or in parallel), the construction and transport sectors are expected to experience rapid growth, with demand for personal mobility predicted to triple by 2030, making India the third-largest transport market after China and the United States (Kapur & Bhattacharjya, 2019). Such growth (in multiple areas in India) is expected to add 30 per cent to global energy demand by 2040 (IEA estimates). To deal with such pressure on various resources, there is a need to not only shift to renewable energy and reduce energy demand, but to also reduce waste production and environmental degradation and shift to sustainable transportation systems.

In response to these challenges, India has taken important steps towards transitioning to a green economy and has made (modest) pledges as part of the Paris Agreement, which was ratified in 2016 (Interview with CEEW, March 2019). As part of its NDCs, India aims to (a) reduce the emission intensity of its gross domestic product (GDP) by 33-35 per cent below 2005 levels by 2030, (b) increase the share of non-fossil-based energy resources by 40 per cent of installed electric power capacity by 2030 and (c) create an additional (cumulative) carbon sink of 2.5-3 gigatonnes of CO_2 equivalent ($GtCO_2e$) through creation of additional forest and tree cover by 2030 (Climate Action Tracker, n.d.).

National level strategies have been developed in various sectors to implement sustainability related programmes. In renewable energy generation, India has seen extensive progress, although coal generation remains high in the energy mix. Energy efficiency has also become a core priority in the past few years and the private sector has been increasingly engaged in reducing energy intensity and its environmental footprint. Actions in other areas such as air and water pollution, transportation and waste management are also increasingly coming to the forefront of policy action in India.

In 2008, India adopted its National Action Plan on Climate Change (NAPCC), which has been integrated into its five-year development planning cycles. Some states are also voluntarily taking measures to integrate the

28 By 2030, the urbanisation rate is expected to rise to 50 per cent from the current 34 per cent (Kapur & Bhattacharjya, 2019).

29 By 2050, India's GDP is expected to increase 10-fold (Purohit et al., 2019).

sustainable development goals (SDGs) of the 2030 Agenda for Sustainable Development into their sectoral level development strategies. The NAPCC identifies measures that jointly promote India's development objectives and address climate change effectively. Eight national missions (long-term and integrated strategies) are part of the NAPCC: the National Solar Mission, the National Mission for Enhanced Energy Efficiency, the National Mission on Sustainable Habitat, the National Water Mission, the National Mission for Sustaining the Himalayan Ecosystem, the National Mission for a Green India, the National Mission for Sustainable Agriculture and the National Mission on Strategic Knowledge for Climate Change. In 2013, the National Electric Mobility Mission (NEMM) was published and later reinforced with two road maps for faster adoption of hybrid and electric cars and offers of support for local manufacturing, closely linked with the "Make in India" initiative. The "Make in India" initiative launched in 2014 (with the goal of making India a global manufacturing hub and encouraging domestic manufacturing) and challenges the private sector to seek environmental solutions by linking sustainability schemes with incentives.

During our fieldwork, it became evident that the pathway of transition to a green economy in India is influenced by different trade-offs between various goals or options, including the following.

- In terms of policy design, there is a perceived tension between policy push versus gradual roll-out of technologies.
- The use of mandatory regulation versus voluntary action in areas related to sustainability and the environment is also highly debated.
- With regards to technology choice, there is debate in various sectors (e.g., waste management, transportation) about whether it should be market or policy driven and the implications such choices would have for lock-in into particular technologies[30].

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30 For example, in the transportation sector, the market (automotive firms) would prefer a transition towards hybrid vehicles (and not electric cars), as the costs may be lower. However, policy makers argue that this may lock-in the sector in less green transportation solutions. Instead, a more radical approach should be adopted to invest in building up capabilities and competitiveness in electric cars. A similar discussion is taking place in the waste-to-energy technology space.

- The engagement of the private sector is still unclear (or suboptimal), with clear trade-offs between a reactive or a proactive approach.[31]
- Lastly, the need for job creation in the process of transitioning to a green economy remains a high priority and a challenge for policy makers.

Addressing these trade-offs would require system-level action, coordination between different strategies and initiatives and building on synergies between various goals.

Overall, despite the comprehensive strategies and numerous initiatives and programmes supporting the transition to a green economy, implementation lags behind in many areas. The main reasons for this are related to

- The complex governance system in India (between central, state, municipal and local levels) and low (sub-national) compliance with national regulations;
- The low capacity for implementation due to understaffing in several public organisations;
- The limited awareness of energy and environmental problems and their consequences;
- The strong price-sensitivity of a large share of the population, which creates trade-offs between cost and reliability of green products and services and prevents large-scale deployment; and
- The challenges for local producers in competing with low cost imports and entering global value chains.

QI services are also suboptimal in several green technology sectors, as we will see below. Given the role that QI plays for competitiveness and sustainability, improving and strengthening these services could facilitate the implementation of policies for transitioning to a green economy.

31 The concern here is that the private sector's engagement with the green economy agenda has been mostly reactive, responding to regulations, which may be associated with higher costs for firms. A proactive approach, instead, would require firms to anticipate future trends in regulation and invest early on in improving the environmental footprint of their activities, thus reducing the cost of compliance with regulations. This approach, however, is more costly for firms.

5.1.1 The NQI system

The NQI system in India is well established and internationally recognised in many areas, and the private sector is substantially involved, particularly in conformity assessment activities.[32] The different stakeholders and their roles are extensively documented by the Indo-German working group on QI presented in a German Agency for International Cooperation (GIZ) report (Singh, Grinsted, Kesari, & Dhundia, 2018). In 2018, the first comprehensive national strategy for QI, the Indian National Strategy for Standardization (INSS), was published. It systematically addresses and integrates the four pillars that INSS believes comprise the QI system: (i) standards development; (ii) conformity assessment, accreditation and metrology; (iii) technical regulation and sanitary and phytosanitary measures; and (iv) awareness, counselling, training and education (Ministry of Commerce and Industry, 2018). The fourth pillar emphasising awareness, education and training has been newly integrated in the strategy. One of the goals of this strategy is to align the various QI activities with other national policies related to trade and industry, as well as consumer and environmental protection.

Green economy aspects have already been integrated in all QI components, although to different degrees, as will become clear below once we discuss various green technology sectors. To easily follow the sectoral analysis and to offer additional system level insights relevant to the development of a green economy in India below we will (a) briefly introduce the main actors in the NQI system in India presented at large by Singh et al. (2018) and (b) present key challenges regarding the overall QI related to the green economy that we found in our fieldwork.

Main QI stakeholders and NQI challenges

Standardisation is primarily led by the national standards body, the Bureau of Indian Standards (BIS), which is exclusively authorised to publish Indian

32 The Confederation of Indian Industry (CII) has an Institute of Quality that assists local companies in becoming competitive internationally by promoting quality improvements in various areas (India Standards Portal, n.d.).

Standards.[33] BIS is a member of ISO and International Electrotechnical Commission and is well connected with other international standardisation groups. There are 352 technical committees at the BIS grouped in 14 divisions, which have published more than 20,000 standards over the years (BIS, n.d.). Various technical committees have been created over the years for issues related to green economy, which developed several standards in areas such as air quality, environmental protection, solid waste management, and sustainable transportation. A technical committee has also been created for Smart Cities, and one standard based on ISO 37120: 2014 "Sustainable development of communities – indicators for city services and quality of life" is currently under development.

BIS also plays an important role in product certification and is responsible for about half of the certifications used in India. BIS has also listed 44 products for compulsory registration (six of these product categories cover solar PV system devices and components, and several other products relate to LED lighting). A large number of private conformity assessment bodies are also present for management systems and foreign certification schemes.

The accreditation system is coordinated by the Quality Council of India (QCI) that has four accreditation boards and is under the administrative control of the Ministry of Commerce and Industry. Two of these accreditation boards relevant to this project are the National Accreditation Board for Certification Bodies (NABCB) and the National Accreditation Board for Testing and Calibration Laboratories (NABL). NABCB and NABL are members of the International Accreditation Forum (IAF) and the International Laboratory Accreditation Cooperation (ILAC), respectively.[34] Overall, 250 certification bodies are currently operating in India as well as 52 accredited inspection

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33 Aside from the BIS, there are also other standards developing organizations (SDOs), such as the ARAI, Building Materials and Technology Promotion Council (for innovative and emerging building materials and technologies), BEE (for energy efficiency standards for appliances, voluntary and mandatory standards, and labelling programmes). Various foreign SDOs are also present in India.

34 More recently, there seems to be a shift towards third party accreditation where there is a need for certifying bodies, including the area of energy efficiency and environmental monitoring (Interview with NABL, March 2019). Inspectors for State Pollution Control Boards (SPCBs) fear competition, however. To enable this process, the Parliament must amend legislation, which is a complex and lengthy process (Interview with QCI, March 2019; Interview with NABL, March 2019).

bodies, 3,700 accredited testing laboratories and around 1,000 accredited calibration laboratories (Interview with QCI, March 2019).[35]

The National Physical Laboratory (NPL), an institution of the Council of Scientific and Industrial Research (CSIR) (the largest network of public research institutions in India, it has 38 laboratories with 4,600 active scientists supported by about 8,000 scientific and technical personnel), is India's national metrology institute, providing traceability for calibration and measurements. The NPL also produces and certifies reference materials. The NPL sees the need for an "investigative approach to identify what reference materials and calibration services are needed as precision measurement is seen to be key in many issues (e.g., hazardous waste, air pollution)" (Interview with NPL, March 2019). Overall, NPL faces capacity constraints as they have limits on hiring and a large part of the scientific staff will retire soon. Also, international cooperation is hampered by time-consuming administrative approval processes through CSIR; as a result, NPL can do inter-laboratory comparisons, but cannot adequately benchmark their work to international standards.[36]

The network of laboratories for legal metrology for weights and measures includes regional reference standard laboratories, secondary standards laboratories at the state level, and working standards laboratories at the inspectorates established at the district level.

In the area of green economy, technical regulations are issued by specific regulatory bodies set up by the government or by the responsible ministries. Examples of such regulatory bodies relevant to our green technology sectors are the Bureau of Energy Efficiency (BEE); the Central Pollution Control Board (CPCB) under the Ministry of Environment, Forest and Climate Change (MoEFCC); and the Automotive Research Association of India (ARAI) under the Ministry of Road Transport and Highways (MoRTH). Although overall, India has – in comparison with the EU – a small number of technical regulations, many are still missing in the area of waste management, for instance, but others have been recently introduced in energy efficiency. Voluntary sustainability standards are not yet of great interest in India.

35 See also NABCB (n.d.).

36 NPL is not currently part of the European Metrology Programme for Innovation and Research (EMPIR) but it does enjoy long-term bilateral relationships with national metrology institutes, such as the PTB (Personal communication with PTB staff, March 2019).

A few main national-level QI challenges can be identified, related to the transition to a green economy[37]:

- There is a need to integrate quality issues early in project design and use a long-term approach starting from product design all the way to end of life, in order to reduce waste and to improve environmental and energy performance.[38] Such an approach is new for most QI stakeholders.
- Policies and regulations are often made without considering measurement and calibration facilities and without consulting NPL in advance in regard to critical measurement-related aspects (Interview with NPL, March 2019).
- BIS has done a lot in terms of adopting a wide range of standards, but many are not adapted to India's climatic conditions (and variations) and some are made without considering measurement facilities available in the country (e.g., related to energy efficiency in buildings).
- Much better traceability of measurement is required in many areas related to green economy as well as reference material for calibration (Interview with NPL, March 2019). International integration and cooperation of NPL India is still limited and hampered by cumbersome administrative processes.
- The public network of CSIR institutes conducts research on various green-economy-related topics (e.g., energy efficiency in buildings, air and water pollution and waste), but, due to limited capacity and resources, "new" sectors and technologies (such as e-mobility, smart grids, biomass and solar PV) lie outside their scope. Limited budget and staff also impact the quality of research in various areas.
- As of 2016, less than 1 per cent of the testing laboratories had been accredited by NABL, which means that accredited laboratories are overburdened and struggling to deliver timely and efficient services (Gupta, Ganesan, & Ghosh, 2016). The accreditations are valid for only two years, after which laboratories have to apply for renewals, which

37 A more detailed assessment of these challenges can be found in the country case study report (Vidican Auktor, 2019a).

38 Reference has been made to the example of solar energy, where the initial target and projects have been deployed without much consideration for quality; this gap has to be addressed now but should be avoided for other technologies (NPL, March 2019; SECI, March 2019).

are costly and cumbersome (Gupta et al., 2016). Tax exemptions and concessions for NABL-accredited labs could motivate non-accredited labs to seek accreditation (Gupta et al., 2016). As we will discuss in the next sections, in some areas of green technologies, the number and services of testing laboratories remain limited (e.g., air pollution, energy efficiency, building materials and waste management).

- Mandatory regulation is still much more important in India than voluntary sustainability standards, except perhaps in the automotive sector (i.e., fuel efficiency), which is export oriented. For this reason, especially in the green economy space, there is a more urgent need for mandatory regulation to enable initial progress.
- Private sustainability standards do exist in India mostly in the agriculture, textile and food sectors; in other sectors this is not yet the case and it is not likely that there will be progress in this direction.
- Conformity assessment and compliance is a weak area in various sectors. Inspection services also suffer from a lack of capacity and capabilities.
- Even if the private sector is well attuned to QI services (more so than in countries such as Morocco), incentives for quality certifications should be linked to sustainability schemes (i.e., programmes aimed at improving environmental sustainability), especially for SMEs.

5.1.2 Air pollution

Exposure to air pollution is a major problem in India, especially in urban areas. About a quarter of the population lives in areas where the World Health Organization (WHO) benchmark limit (of 10 $\mu g/m^3$) is exceeded more than nine-fold (Purohit et al., 2019). WHO's Urban Air Quality Database lists 10 Indian cities among the world's top 20 most polluted cities (WHO, 2016). The health effects from these high pollution levels are substantial and caused about 8 per cent welfare loss in 2013 (World Bank, 2016c). [39]

Key to reducing air pollution is improved monitoring and evaluation of these emissions, a faster adoption of standards, education and awareness on

39 Precise data is often lacking, but estimates suggest that between 483,000 and 1.3 million cases of premature deaths from outdoor pollution and between 748,000 and almost 1.3 million cases of premature deaths from indoor household pollution occur annually in India (several sources in Purohit et al. (2019, p. 2)).

consequences across population groups, and improvement in compliance. Effective monitoring and evaluation of air pollution is particularly crucial for improving air quality and for the effectiveness of regulation.[40] The CPCB is the entity within the MoEFCC responsible for implementing pollution-related regulations (for air, water, noise and waste management). In 2018, the National Clean Air Programme (NCAP) was launched with the objective of reducing particulate matter (PM) concentrations PM2.5 and PM10 by 20-30 per cent by 2024 and augmenting the air quality monitoring network. By the end of 2018, 80 cities across India had developed their air pollution action plans (Chatterjee, 2018). Under the National Air Quality Monitoring Programme (NAMP), three main air pollutants are being monitored: sulphur dioxide, nitrogen dioxides and respirable suspended particulate matter.

Out of the 5,000 cities and towns of India, a regulatory monitoring network exists only in 260[41]; out of these, only 24 cities have some capacity to do real time monitoring (CSE, 2016). Our interviews suggest that about 700 monitoring stations are installed across India, but only 117 can monitor air pollution in real time; the others are out of order or must be operated manually (Interview with Shakti Foundation, March 2019). Manual monitoring is inefficient, vulnerable to weak quality control and results in inordinate delays in data reporting, making data irrelevant for public health protection (CSE, 2016).

Due to poor maintenance of these monitoring stations, the magnitude of the air pollution problem is not yet fully understood and much more needs to be done to calibrate equipment and allow for real-time measurements as well as to analyse the data collected from various locations. Setting up and operating functioning monitoring stations is expensive and requires extensive capabilities. Metrology services are essential for this purpose; monitoring instruments must answer to quality standards (e.g., calibration), as the results must be traceable. A whole chain of quality control is necessary, from instrumentation to calibration, to inspection and reporting (Interview with NILU, January 2019). In the Indian context, resources and capabilities remain limited in this area (despite the large network of monitoring stations) due to failures in operation, maintenance and implementation.

40 This issue is also closely aligned with PTB's mandate and former project activities on quality assurance of chemical measurements.

41 China, for example, has 1,500 online PM 2.5 monitoring stations in 900 cities and towns, compared with 39 stations in 23 cities in India (AQI, 6 May 2019).

In advanced economies, air pollution assessments rely on combining data from four main sources, each providing different levels of accuracy: monitoring stations, satellites (offering macro-level data), modelling and, increasingly, microsensors or low-cost sensors (offering micro-level data). The sensor technology for measuring air quality is still a relatively new technology in Europe and the United States. However, this technology offers the most accurate measurements, allowing for measuring variation in concentrations over space and time (NILU, March 2019).[42] Therefore, most innovation and technology development is expected to be seen in this area (i.e., low-cost sensors) in the coming years. Standards at the European level are also under development (part of the European Air Quality (AQ) directive) and various working groups are active in this space.[43]

Given these global trends, low-cost sensor technology is also increasingly used in India.[44] As sensors offer 90-95 per cent accuracy compared with stationary monitoring technologies, and as they are a cheaper alternative, the deployment of this technology in India is expected to grow in the coming years. One low-cost sensor costs about INR 15,000 (approximately EUR 193), which is much lower than the cost of a monitoring station of about EUR 120,000 to which maintenance costs (of about EUR 13,500) have to be added; the operation of monitoring stations also requires higher technical capabilities compared with sensors (Interview with Shakti Foundation, March 2019).

The low-cost sensors used in India are procured from the free market (mostly from China and the United States) and assembled locally. However, the product quality is low and there is low confidence in their measurements (Interview with NEERI, March 2019). Adaptation of this technology to India's various climate zones is necessary. The Indian Institute of Technology (IIT)

42 As per NetMon (2019) "novel low-cost sensor technologies are poised to support a paradigm shift by allowing ubiquitous ambient pollution monitoring with high spatiotemporal resolution available at every person's fingertips – either through environmental information websites backed by stationary and mobile sensor networks or quite literally with sensor technology being integrated into mobile devices and supported by Internet of Things."

43 Such working groups include CEN Technical Committee 264 on ambient air quality sensors and FIMEA working group on air quality micro-sensors certification (Universität des Saarlandes, 2019).

44 Shakti Foundation has also founded a project that installed 250 sensors in 150 cities in the past year. Twenty sensors were installed in 2017 in New Delhi as part of a pilot project.

Kanpur together with Sonoma Tech (a US company) is currently developing a reference grade monitor for sensors measuring PM2.5, which will give a correction factor that can be used for calibration purposes (Interview with NEERI, March 2019). Other IITs are also doing local calibration, but the instrumentation they use is not always up to date.

To ensure consistency across measurements, CPCB should be much more involved in this area. Yet, CPCB needs not only more technical knowledge but also higher budgets and more technical staff.[45] There is a large disparity between capabilities not only across states but also between national, state (State Pollution Control Boards (SPCBs)), and local organisations, which ultimately hinders implementation and enforcement.

Overall, QI in this area remains insufficient. Much more needs to happen on standards, calibration and certification, to offer a common platform across users of the technology (Interview with CEEW, March 2019). Two problems, however, are non-compliance (102 cities have been identified as non-attainers of the clean air action plans) and poor measurements (Interview with Shakti Foundation, March 2019).

5.1.3 Energy efficiency in buildings

Energy efficiency is an area with a lot of potential for reducing emission intensity of GDP in India, both in the industrial and the building sector. The BEE, established in 2002 through the Energy Conservation Act under the Ministry of Power, is the main actor tasked with conceptualising, coordinating and implementing a range of energy efficiency policies. Its programmes are targeted towards energy efficiency in buildings, the industrial sector and the transport sector, through standards, labelling and certification. Another important stakeholder is the Energy Efficiency Services Limited (EESL), which is the energy services company of the Government of India and the largest public energy services company worldwide. As such, EESL is the implementing agency for the National Mission for Enhanced Energy Efficiency (NMEEE).[46]

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45 CPCB has only about 200 staff members at the national levels. Increasing manpower is, however, difficult as special approvals from the Ministry of Finance are needed. SPCBs also need to be strengthened, but they cannot receive more funds (Interview with MoEFCC, March 2019).

46 NMEEE is one of two national missions under the NAPCC.

Several programmes and initiatives related to energy efficiency have been rolled out or are in planning phase. Energy efficiency measures across all sectors, but especially in the building sector are key for India to achieve its target of reducing emissions by 33-35 per cent by 2030 from its 2005 level.

An initiative that has already been successful is the Unnat Jyoti by Affordable LEDs for All (UJALA) programme, which was implemented in 2012, seeking to deploy 800 million LED lights across the country. As a result of competitive bidding processes, 260 million certified LED lights have been sold and the price per light was reduced from USD 5 to less than USD 1 in 2016 (CLASP, 2016). The UJALA programme also enabled India to design and implement the world's first LED light standards; in 2016, BIS also developed the first LED street lighting luminaries standard (CLASP, 2016).

A large potential still exists for energy efficiency, specifically in the buildings sector. First, the increasing use of air conditioning units, especially in commercial buildings, will put growing pressure on energy consumption (Mathur, 2019). By 2030, air conditioning will represent over 30 per cent of energy demand in residential buildings and up to 75 per cent in commercial buildings (Mathur, Shekhar, Sethi, & Kumar, 2018). Second, a rapid growth in buildings and built space is expected in India. BEE claims that more than 50 per cent of the building stock that will exist in 2030 is yet to be built (BEE, n.d.-b). Others argue that even two-thirds of India's commercial and high-rise buildings that will exist in 2030 are yet to be built (Kumar, Kapoor, Rawal, Seth, & Walia, 2010) and that Indian building energy demand (and CO_2 emissions) could increase by as much as 700 per cent by 2050 compared with 2006 levels (GBPN, 2014). Thus, as electricity consumption is expected to increase seven-fold by 2032 and the building sector is expected to become the largest consumer, energy efficiency in newly constructed buildings is considered key.

Two main programmes have been implemented to reduce energy consumption: the Energy Conservation Building Code (ECBC) and the Energy Efficiency Standards and Labelling Programme by the BEE. The ECBC is the main regulatory framework for energy savings, providing minimum (voluntary) standards for energy performance (in design and construction) in commercial buildings. The ECBC includes prescriptive requirements for building envelope and equipment mitigation technologies (such as wall and roof insulation, advanced window technologies, roof coatings, space heating, cooling, lighting, etc.) (Khosla, Sagar, Mathur, 2017, based on the ECBC). The 2016 National Building Code (NBC) of India is the reference standard for lighting levels, HVAC, thermal comfort conditions, natural ventilation, and any other building materials and system design criteria relevant to the ECBC.

Currently, only 17 states have adopted the code (out of 36 entities, including 29 states and seven union territories) mainly due to a low capacity for implementation.[47] India also has a very complex environment when it comes to energy consumption, as it has five climate zones and some states are located in more than one climate zone. As a consequence, the implementation of the national ECBC has to be customised to the local environmental conditions, which is a challenging undertaking for under-staffed state-level administrations.

Another important programme implemented by the BEE has been the star rating programme for standards and labelling for 22 electrical appliances (for 10 of these products, including ACs, the energy performance standards are mandatory).[48] For these products, performance testing is conducted in an NABL accredited laboratory or at the BEE laboratories (BEE n.d.-a). To support the deployment of green technologies in this area, EESL has also promoted utility-driven models for exchanging air conditioning units (together with BSES Yamura Power Limited, a power distribution company) and incandescent light bulbs. The air conditioning unit programme was, however, not very successful, mainly because of demand issues.[49]Another set of initiatives with relevance for this sector is green building codes,[50]

47 In the interview with the Shakti Foundation (March 2019), it was mentioned that only 5-10 per cent of those who should have adopted the ECBC in the commercial sector have done so, which is lower than the above statistic. Therefore, there seems to be a large potential to further grow the market.

48 The list of products under mandatory standards are room air conditioners, frost-free refrigerators, tubular fluorescent lamps, distribution transformers, residential air conditioners (cassette, floor standing tower, ceiling, corner air conditioning units), direct-cool refrigerators, electric geysers, colour TVs, IAC notifications/gazettes, LED notifications/gazettes (BEE, n.d.-c)

49 The programme was apparently rolled out in two communities in Delhi, where 4,000 and 6,000 units were supposed to be replaced, respectively. But fewer than 2,000 were deployed (Interview with Shakti Foundation, March 2019).

50 Indian Green Building Council's (IGBC) green building rating system is a voluntary scheme. Another rating tool for green buildings has been developed by TERI jointly with the Ministry of New and Renewable Energy (MNRE): the Green Rating for Integrated Habitat Assessment (GRIHA).

which, however, have limited uptake still, as until recently they were not mandatory.

The ECBC building codes along with the other initiatives in the private sector and in the area of green building certification are likely to have two main market impacts: (a) localisation of production for energy efficiency products (e.g., air conditioning) and (b) demand for local building materials is expected to increase further as these codes see higher adoption rates. As BEE has set higher labelling standards for imports of air conditioning units, local manufacturing of these products is expected to grow (currently less than 50 per cent of air conditioning units are locally produced); LEDs, initially imported from China, are now mostly manufactured in India (except the LED chip) following the large public procurement programme in this sector (Interview with TERI, March 2019).

Large opportunities also exist in the use of local materials for energy efficiency in buildings. To this end, BEE is currently working (with the support of GIZ) on developing a Building Material Directory that would provide detailed information for builders and manufacturers on the energy performance required for various building materials; this would also assist QI stakeholders in extending and diversifying their portfolio of services in this sector.[51] In particular, such a directory will create a need for testing laboratories (The Energy and Resources Institute (TERI) has already set up some testing facilities for building materials in relation to their own green buildings programme called the Green Rating for Integrated Habitat Assessment (GRIHA)) (Interview with BEE, March 2019).

Red bricks, fly ash bricks (manufactured from waste from coal power plants) and autoclaved aerated concrete (AAC) blocks are, for instance, increasingly produced by local SMEs and are supposed to offer better energy performance and durability than conventional products. Such products are already in high demand on the Indian market. However, QI services are severely lacking in this area, that is, a lack of standards, metrology and conformity assessment, which hinders production and large-scale dissemination. Fly-ash bricks are, for example, mostly produced by SMEs. Without standards in place, quality

51 Such a guide complements other initiatives such as the Product and Policy Analysis Tool (PPAT) created by CLASP and Environmental Design Solutions (EDS) to inform policy makers about which products to include in India’s standards and labelling programme based on potential energy and cost savings (Interview with EDS, March 2019; CLASP, n.d.).

varies extensively across producers. Construction and demolition waste can also be used in the production of bricks and concrete chips. Testing labs for building materials exist, but they are too few. One such example is at CEPT University (formerly the Centre for Environmental Planning and Technology), which is considered to have the best and most comprehensive testing facilities in India for building materials (Interview with Shakti Foundation, March 2019). Other testing facilities exist at the Centre for Science and Environment (CSE), TERI, IIT Delhi, and at the Jaipur University, but only for some limited aspects. CEPT University has been testing 80 commonly used walling blocks from eight states in India. Once the results are finalised, more information on the thermal performance of these products will be available, which will then inform QI stakeholders on how to develop relevant services (e.g., standards and certification schemes). Certification as well as market surveillance are weak for such products and need to be strengthened.

In summary, QI services are very much needed in the sector of energy efficiency in buildings. First, many more NABL accredited facilities are needed for testing laboratories and proficiency testing providers will be required in India (even for air conditioning, testing labs are insufficient and for other products and materials the situation is even worse). The testing laboratories should be accredited for the ISO/IEC 17025 and NPL, or other specialist laboratories should have appropriate reference standards to ensure traceability for the respective areas; samplers should be fixed and then tested at different labs (Interview with BEE, March 2019). Calibration services are also seen to be insufficient. Moreover, there is a wide difference in the performance of testing and calibration laboratories (even for the NPL labs), which decreases confidence in the results.[52] Primary calibration is also missing in this sector (Interview with Smart Joules, March 2019). Labelling and certification programmes are well developed but increasing awareness, implementation at state level and aggregation of demand could further contribute to the deployment of energy efficiency products and processes. There is also a need to improve compliance, monitoring and reporting of energy efficiency information (Interview with Smart Joules, March 2019).

52 Apparently, some certification programmes have been stopped because of poor results from testing labs (Interview with BEE, March 2019).

5.1.4 Sustainable transportation

Rapid urbanisation and increase in population and incomes in the past decades has contributed to an increase in transport demand by eight-fold since the 1980s in India, which is higher than in any other Asian country (Juyal et al., 2018). These same trends will contribute to further transformations in the transportation sector, especially given its impact on air pollution (as discussed earlier). Since the 1980s, the number of registered motor vehicles has grown from 5.4 million to 210 million in 2015 (a 40-fold increase) (Juyal et al., 2018). Still, only about 8 per cent of the population in India owns a car, and by 2040, the number of vehicles on the road is expected to double (Interview with EESL, March 2019). To deal with this joint challenge of increase in demand for mobility and clean air, the sustainable transportation sector (especially electric vehicles and hybrid vehicles) recently came into focus in India. Other solutions, such as inter-modal transportation have either been unsuccessfully tested in different locations or are considered unsuitable for the Indian context. Emission norms have also been made more stringent (shift from Bharat Stage (BS) IV to BS VI (equivalent to the Euro 6 standard)) since 2018 and OEMs have already invested in upgrading facilities (Interview with CEEW, March 2019).[53] The 2018 amendments to the Central Motor Vehicle Act also make these emission standards mandatory (The Economic Times, 31 July 2019).

MoRTH announced in 2017 that it aims to increase the share of EVs from its current share of about 1 per cent to nearly 30 per cent by 2030, while the share of electric buses could be expected to rise as high as 100 per cent.[54] More recently, in June 2019, it was proposed that after 2030, only EVs should be sold on the Indian market, expanding the scope of clean fuel technology beyond two- and three wheelers (Dash, 18 June 2019). An e-highway programme is also being discussed as well as a plan to manufacture 50-gigawatt-hour batteries by 2030 (Dash, 18 June 2019). A local content of 40-60 per cent is also targeted for EVs and the focus is on low-cost automation and last-mile connectivity (e.g., installing charging

53 See also embitel (n.d.) for challenges related to adopting these standards.

54 The automotive industry is a USD 52 billion business in India, more than half of which comes from exports (Interview with ACMA, March 2019). India’s annual vehicle production is over 25 million; 79 per cent of those vehicles are two-wheelers, followed by passenger vehicles (14 per cent) and commercial vehicles (7 per cent), the rest are three-wheelers, light commercial vehicles and heavy duty vehicles (Bhattacharjya et al., 2018, based on data from SIAM).

stations in public transportation areas, increasing the public vehicle fleet of e-vehicles) (Interview with ACMA, March 2019; Dash 18 June 2019). The expectation is that by 2030 the total estimated number of electric two wheelers on Indian roads will be more than 200 million, and electric cars and buses will number 34 million and 2.5 million, respectively. As of March 2018, India had 448,000 EVs on the road, of these 7,000 were four-wheelers and 150 were heavy vehicles, like trucks and buses; 90 per cent of total EV sales were two-wheelers (Tripathi, 5 August 2019). By now, there are also about 1.5 million electric three-wheelers (e-rickshaws) on the road (Bhatia, 20 March 2020). The key challenge, however, is competing with China, as its presence is expanding fast in India (e.g., Shangai China has purchased GM India, and BYD is already active in India, as well as several battery manufacturers).

Several states (such as Andhra Pradesh, Karnataka, Maharashtra, Telengana and Uttar Pradesh) have also already declared plans to promote EVs and support domestic manufacturing (Bhattacharjya et al., 2018). Karnataka aims to develop EV manufacturing zones, infrastructural capacities, charging systems, and acquire tax exemption on EVs and set up battery swapping stations (Bhattacharjya et al., 2018). Most states realised, however, that their initial targets (and orders) of EVs (mostly buses) have been too large to be satisfied by any supplier (e.g., Bangalore ordered 2,000 e-buses); therefore, they are shifting to more gradual approaches (Interview with KfW Bankengruppe, March 2019). Moreover, for these public procurement programmes to be carried out, pre-delivery inspection (PDI) services are needed, which would be carried out based on pre-determined specifications. However, while for conventional vehicles these services are widely available, for EVs there are currently hardly any institutions offering such inspection services (Interview with KfW Bankengruppe, March 2019).

The programme created to speed up the deployment of EVs and hybrid vehicles in India has been the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) (launched in 2012) under the NEMM 2020. The initial result was to increase the share of hybrid and electric passenger vehicles sales from zero to 1.3 per cent by 2016. Several incentives accompanied these programmes, such as tax incentives on battery-based electric drive trains. The government has committed to procuring 10,000 electric buses for its own use,[55] and is providing incentives of 60 per cent of the cost of a bus (or INR 1 million, about EUR 12,560) for those products that have localised at least 35 per cent of the content (Bhattacharjya et al., 2018). In early 2019, the second phase of the FAME programme (FAME II) was rolled out, which offers higher incentives for EV adoption. These two schemes are expected to have a strong impact on local manufacturing of EVs.

Leading EV local manufacturers include Hero Eco, Mahindra Reva (with its E2O and Verito models), Electrotherm, Avon, Lohia, Ampere and Tata (with its Tigor model); they produce a range of EVs (scooters, cars, buses, mini pickup trucks, rickshaws and bicycles). Other companies such as Maruti Suzuki, Tata Motors, Nissan and Toyota have also expressed interest in the EV market in India. However, the 30 per cent by 2030 target set by the government is considered too low for many companies to engage in large investments to scale up their operations (Interview with The Climate Group, March 2019). Electric three-wheelers have a longer history in India in terms of production and use. This market is considered to have a large potential not only for sales in India but also as an export product to South Asia and Africa.

The EV ecosystem in India is already quite well developed, as most stakeholders and services are present. The scale of deployment remains low, however, but it is expected to grow in the coming years especially in public transportation and commercial sectors (i.e., fleet operators, such as airports, utilities and taxis). There is some push-back from the local parts and components manufacturers as the Automotive Components Manufacturers Association (ACMA) estimates that about 1.5 million jobs would be lost (Interview with CEEW, March 2019; Interview with ACMA, March 2019). However, as the Council on Energy, Environment and Water (CEEW) finds in a new modelling study on gains and losses from EVs in India, new job opportunities arise in areas such as telematics, power industry, battery and after-sale services (Interview with CEEW, March 2019).

A key stepping-stone and challenge in the deployment of EVs (aside from battery cost and performance) is the set-up of a large network of charging stations. Local manufacturers for charging stations are already present, along

55 EESL is tasked with rolling out this programme. However, to date, only 2,000 buses have been deployed and the programme's performance remains weak. New Delhi has planned to purchase 1,000 e-buses, but the target is considered unrealistic for the reasons mentioned earlier (Interview with KfW Bankengruppe, March 2019).

with Chinese, Japanese and European producers (Interview with BIS, March 2019). Several charging stations have already been deployed, mostly as pilot projects and there are also plans to install 300 charging stations in the very near future in Delhi (Interview with ACMA, 2019).[56]

Other challenges relate to the QI services, such as standards, testing and calibration facilities, and to inspection services for the EVs. Following the NEMM, BIS established a technical committee for electric and hybrid vehicles (TE27: E-Vehicles) and for cars running on alternative fuels (TE26: CNG/Hydrogen). BIS is also a member of the ISO Technical Committees 22 and 41 for non-conventional fuels/cars. The Automotive Research Association of India (ARAI), based in Pune, is leading these committees and is responsible for the homologation of standards and for the testing labs (Interview with BIS, March 2019). For EVs, BIS has developed a code of practice and several standards are currently under development (for lithium-ion batteries, safety requirements, measurement of energy consumption, measurement of range power, etc.). Currently, Chinese standards are used for most products, but they are not suitable for the Indian environment (Interview with CEEW, March 2019). Standards for charging stations are also under development (one set of standards has already been adopted by a so-called sectional committee).

Given the well-established automotive industry, QI services such as testing, certification, research, calibration and standardisation are well established in the conventional car sector. Some of these services could perhaps be diversified to alternative transportation technologies. In fact, ARAI has established a technology group working "on futuristic indigenous technologies to enable safe, sustainable and smart mobility solutions" (ARAI, n.d.-a; n.d.-b), and it presently also has the only testing facility for charging stations (Interview with EESL, March 2019). Other testing facilities also exist at IIT Chennai and IIT Bangalore, but their products are not market tested, which is relevant for state institutions that want to do public procurement (Interview with KfW Bankengruppe, March 2019). Further, pre-delivery inspection services are missing for EVs (while for conventional vehicles, these are widely available), slowing down deployment programmes (Interview with KfW Bankengruppe, March 2019).

56 BSES has already installed four charging stations for their two EVs (they plan on having five EVs to service their clients). BSES also seeks to convince railways to allow them to install charging stations in parking areas (Interview with BSES, March 2019).

5.1.5 Solid waste management

Waste generation and inadequate waste collection, transport, treatment and disposal are increasingly posing environmental and health hazards in India (Kumar et al., 2017). Despite the rising amounts of solid waste generated by the growing population and its consumption, the solid waste management systems have remained mostly unchanged over the decades. The urban areas in India produce approximately 170,000 tonnes of waste daily, and this is expected to increase by 5 per cent each year (Planning Commission, 2014). About 62 million tons of municipal solid waste are generated per year; only 43 million tons are collected, 11.9 million tons are treated and 31 million tons are dumped in landfill sites (Lahiri, 8 May 2019). By 2048, 125 million tons of waste are expected to be generated, which would make India the largest waste contributor worldwide (Kshourad, 15 November 2017). A large informal sector also plays a key role in waste management in extraction of value from waste (Kumar et al., 2017).

At the national level, in 2014, the prime minister initiated the Swachh Bharat Mission (Clean India Mission) seeking to raise awareness and mobilise communities to reduce waste and improve sanitation.[57] CPCB is the regulating body for waste management. CPCB publishes so called "Waste Management Handling Rules" (issued in 2000 and updated in 2016) for collection, segregation, recycling, treatment and disposal of several types of waste: hazardous waste, municipal solid waste, biomedical waste, plastic waste, e-waste, batteries, and construction and demolition waste. Interviews also suggest that the management of some types of waste, such as plastic bottles, glass, and biomedical waste, is relatively well organised either because of the presence of private operators (as in the case of biomedical waste) or because of value creation opportunities (for plastic and glass).

Across the sector, however, the challenge is not a lack of regulations, strategies and procedures, rather, it is a matter of organisation, availability of recycling infrastructure, capacity of implementation at different levels of government, enforcement and monitoring. Policy is made at central level, but it is municipal authorities that are responsible for implementing these rules and developing infrastructure for collection, storage, segregation, transportation, processing and disposal of waste. Financing is also a key

57 As a result of this initiative sanitation-related issues received more attention, but there is still generally limited interest in waste management related problems (Interview with NABL, March 2019).

issue for municipalities as tax revenues are low at this level (Interview with TERI, March 2019). Lack of knowledge and awareness (especially related to segregation at source) are major issues, along with compliance. If segregation of waste is not properly done, treatment and waste-to-energy technologies are less effective (i.e., has a lower energy recovery). Various examples were given in our interviews, ranging from scrap metal to e-waste and construction and demolition waste. Until these problems are fixed, the performance of various already existing technologies (e.g., low caloric efficiency of waste to energy technologies) or the adoption of more advanced technologies for waste management will be hampered.[58] Public procurement and engagement of the private sector could be game changers in this sector because public entities may link their procurement to suppliers that offer end-of-lifecycle solutions for the procured items.

Moreover, QI services remain weak at different levels (Interview with ToxicsLink, March 2019; Interview with NEERI, March 2019; Interview with NABL, March 2019). First, standards for certain types of waste, such as lead, paint and microplastics, are missing. It is also thought that standards should be made mandatory in this sector, at least for a certain period of time, as was the case for some products related to energy efficiency in buildings. BIS is a member of ISO Technical Committee 297 "Waste collection and transportation management" and is currently working on standards related to "reuse and recycle", converting waste to fuel (it might take about two years until publication), and machines for separation and recycling of waste (Interview with BIS, March 2019). On e-waste, BIS has a standard for how to segregate waste but not for how to process it. Ecolabelling, testing and certification of recycled and reused products are also lacking. The quality of existing laboratories is low. Conformity assessment is weak. Some basic parameters are available but testing and inspection are poor. Characterisation of waste and materials is necessary (e.g., to support product-based specifications for reuse of waste from construction and demolition into other materials, such as bricks, or from scrap metal into the production of various types of equipment or in construction).

58 NEERI and TERI mentioned that they do not support the promotion of waste to energy technologies in India because the efficiency is only 30 per cent (combustible) because of the large share of wet waste (Interview with NEERI, March 2019; Interview with TERI, March 2019).

In this sector, however, immediate action is needed on improving awareness and education, strengthening capabilities for implementation at state and municipal level, and monitoring and evaluation. Streamlining waste management for different types of waste is also key. At the same time, gaps in QI services need to be addressed for effective results. But, without effective management of this sector, the QI services will not be of value.

5.1.6 Overall implications for NQI interventions

The transition to a green economy is highly complex in an environment such as India's economy. However, our field research combined with a literature review allowed us to identify several aspects related to existing challenges and opportunities in the selected green technology sectors. This assessment also suggests potential entry points for national and international QI actors in diversifying their portfolio of projects to support the transition to a green economy in India in the coming years. Sectors such as air pollution monitoring and assessment and energy efficiency in buildings are particularly relevant and interesting entry points in the short- and medium term. The EV sector is also expected to see fast growth (first for the commercial fleets of cars) in the medium term and associated QI services will be increasingly needed. The waste management sector is presently struggling mostly with regulatory and coordination issues; for this reason, traditional QI interventions are expected to be more limited but will perhaps increase in the future.

Below, we summarise the main opportunities and challenges in each of the examined sectors.

Air pollution

- The National Clean Air Act has played an important role in calling for urgent action on improving air quality at the national level. Moreover, CPCB has standards in place, and some cities have taken the initiative to develop clean air action plans. But still, there is low emphasis on this issue outside of New Delhi and in rural areas, mainly because of low levels of awareness on scale and consequences not only in the larger population but also among policy makers and regulators.
- A large network of monitoring stations and testing labs exists, and installation of low-cost sensors has also begun. Research institutes are building know-how on modelling and data analysis of data collected

from these sources. However, the performance and quality of monitoring stations is very low, and the quality of sensors used on the Indian market is poor. These shortcomings create opportunities for increased certification of sensors.

- To increase the profile of the air quality problem in India, cooperation with a more diverse set of stakeholders (such as non-governmental organisations (NGOs) and education and research organisations) is needed. This would also facilitate the transfer of information from measurement stations to the public. International cooperation to build testing capabilities for low-cost sensors would also be necessary.
- There is a clear need to improve the reliability of monitoring stations (testing and calibration), develop new reference materials for pollutants (i.e., means for calibration), and improve the validity of data from low-cost sensors. Inspection services also need to be improved as well as the capabilities for maintenance of these monitoring systems. As low-cost sensors are relatively new on the market, standards and calibration services are needed.

Energy efficiency in buildings

- Several strategies and programmes have been initiated in the past few years that are aimed at enabling energy efficiency in buildings and in industrial processes, such as the Energy Conservation Act, ECBC for commercial (and more recently for residential) buildings, the National Buildings Code, and the Perform, Achieve and Trade (PAT) scheme. Moreover, mandatory audits have been included in the PAT scheme and are currently prepared for buildings. The main challenge in this area is, however, the implementation of these policies and regulations and the scale-up of currently successful programmes, mainly because of governance issues at the state and municipal level. Moreover, energy efficiency programmes in the residential sector are made more difficult by the presence of split incentives (between the builder and owner/tenant).
- Technical expertise in this area exists in firms and universities, but weaker expertise exists regarding architecture of passive design.

- To scale up existing initiatives, cross-ministerial engagement as well as closer engagement with financial institutions is necessary, especially when it comes to energy efficiency in buildings for the residential sector.
- A large number of standards as well as green buildings certification schemes and rating programmes for appliances have been developed in this sector. Calibration facilities for appliances and building materials and testing labs for basic building materials have been created. But these facilities are not sufficient and there is low confidence in energy performance measurements. Additional testing and calibration services are needed and NPL should play a strong role given that reliability of measurements is a key bottleneck. Accreditation of more facilities is also needed. Further, more research is necessary on advanced materials and technologies related to energy efficiency. To ensure reliability, training and certification of installers and third-party inspection in the certification of buildings is necessary.

Sustainable transportation

- Strong national commitment has been expressed in shifting towards sustainable transportation and reducing emissions in this sector through the Central Motor Vehicle Act, the FAME I and II strategies, Bharat State IV, and the Green Vehicle Rating programme for two- and three-wheelers. Some states have also already committed to EV policies with public transport and fleet operators. While some jobs are considered lost as a result of this transition, new jobs will be gained in related services.
- Strong knowledge capabilities already exist in India's well-developed automotive sector; over the years, several capabilities have also been developed in several parts of the EV supply chain. But several challenges remain with respect to battery manufacturing, cost and performance of imported batteries. Charging infrastructure for EVs is also to be rolled out.
- Coordination across several actors is needed for large-scale deployment of charging stations and uncertainties remain regarding impacts on the grid.
- Some standards have been adopted or developed on alternative fuels, batteries and charging stations, but much more needs to be done to keep up with international standardisation in this sector. Some testing and

calibration services exist in the automotive sector, but such facilities are needed for charging stations, vehicle emissions, and quality of fuel. Moreover, research is needed on lithium-ion batteries as well as associated QI services for increasing performance. Fuel economy labelling programmes for passenger cars are underway at BEE and there is some R&D on alternative fuels.

Waste management

- Recycling processes for some materials (such as glass and plastics) are considered to work relatively well and e-waste collection targets have been set for electronics companies. But major challenges exist in waste collection and segregation at source, which hinder the efficiency of technologies, such as waste to energy conversion. A comprehensive strategy in the waste management sector is yet to be developed and regulations are considered insufficient. The financial viability of waste management solutions is also seen to be low. Public procurement could play a key role in this sector.
- There are some good examples of technologies for waste separation and processing, and research also exists on some technologies for waste to energy, anaerobic digesters and composting, for instance, but is missing on technologies for recycling of lithium-ion and zinc oxide, for example. Also, imported technologies need to be adapted to local conditions and the type of waste, which calls for appropriate QI services.
- Most challenges in this sector relate to the organisation of processes and coordination between different levels of governance. A stronger engagement of the private sector in a circular economy approach is also considered necessary.
- Some standards are in place and others are in preparation, but there is a lack of standards for some types of waste, such as hazardous waste and recycled materials. Testing and calibration services for special types of waste (such as construction and demolition waste and e-waste) are necessary.

5.2 Morocco

Morocco, a low-middle-income country in North Africa, is a suitable case to explore opportunities and challenges of transitioning to a green economy for several reasons. With an increasing population and urban agglomeration, a stable economic growth path and limited natural resources (e.g., fossil fuels and water), Morocco has already started experiencing the negative effects of unsustainable growth patterns on its environment (pollution of air, water, and soil and desertification) and on its energy security.[59]

Recognising the severity of these problems and supported by intensified international action towards addressing climate change, Morocco has become highly proactive in its commitment to a green economy and to reducing GHGs (by 42 per cent below business-as-usual levels by 2030, as per its NDCs). Also, in July 2011, a newly adopted constitution reforming Morocco's institutions identified environmental issues as a national priority, establishing the "right to sustainable development" for every citizen (Kingdom of Morocco, 2012).

Several national level strategies have been developed (such as the National Sustainable Development Strategy and the National Strategy for the Environment) as well as sectoral level strategies oriented towards achieving the transition towards the green economy (such as the National Energy Strategy, the National Water Strategy, the National Waste Management Strategy and the Green Agriculture Strategy). New agencies were created (e.g., Moroccan Agency for Sustainable Energy, Moroccan Competence Centre for Climate Change). New laws and environmental regulations have been adopted, structures of key institutions have been reorganised (e.g., realignment of responsibilities at the ministerial level), and new curricula, educational and training programmes have been initiated. In addition, mechanisms of inter-organisational cooperation have been set up; and, generally, stakeholders at all levels (e.g., industry) have been challenged to identify opportunities to consider the environment in their activities. Following the Paris Agreement on climate change, Morocco also adopted some of the most stringent targets for GHGs and developed a wide set of actions and programmes as part of its NDCs (Ge & Levin, 2018). This demonstrated commitment, especially since 2010, has attracted large

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59 Morocco imports more than 90 per cent of its energy needs in the form of natural gas, coal and electricity. Of its total primary energy consumption, 93 per cent comes from oil, natural gas and coal (RECREE, n.d.).

international finance sources, especially in the renewable energy sector, but also in other areas.

These initiatives are recent and capacities for implementation, coordination and monitoring need to be strengthened.[60] Nevertheless, these framework conditions suggest that Morocco is well positioned to advance on its efforts towards greening its economy. Parallel efforts to develop its NQI system as a whole and its green sectors in particular also contribute to this assessment.

5.2.1 The NQI system

Relative to the case of India, the NQI system in Morocco is not only less developed but also less documented. In the past years, however, improvements can be observed following Morocco's increasing participation in global value chains (GVCs). For sectors that are more export oriented, such as textiles, food, and automotive, QI services and inter-stakeholder links and dynamics are better established.

The NQI system is under the coordination of the Ministry of Industry, Trade and Green and Digital Economy (MIICEN) (hereafter Ministry of Industry), specifically of the Department for Consumer Protection, Market Assessment and Quality (DPCSMQ). In 2010, a new organisational body was created: the High Council for Standardization, Certification, Accreditation and Promotion of Quality (CSNCA). The CSNCA suffers from certain weaknesses, however, as it lacks coordination power and has only met once since its inception. An NQI strategy has not been created yet, but interviews suggest that it is currently under development (Interview with TÜV Maroc, November 2018; Interview with LPEE, November 2018).[61]

An NQI strategy and a well-functioning CSNCA are necessary given not only the cross-sectoral nature of green economy interventions, but also the need for incentives and market creation initiatives for green technologies. For instance, for testing labs to acquire necessary equipment, standards need to be adopted and certification services need to be in place. Technical

60 This is to be expected in a developing country context, and especially in the case of Morocco because there are hardly any reference cases for it to learn from, that is, low- and middle-income countries that have successfully transitioned towards sustainable development patterns.

61 This strategy seems to initially focus on three ecosystems: building materials, electronics products and plastics (Interview with TÜV Maroc, November 2018).

regulation can also play a role as, through their mandatory nature they can ensure a market for QI services and contribute to consumer protection (e.g., by setting adequate levels for health and safety concerns).[62] A national strategy and a coordination body such as CSNCA could ensure that these elements of the NQI system are synchronised.

In the area of accreditation, the National Committee for Accreditation (COMAC)*,* which comprises sector-level accreditation committees, was created in 2001 and restructured in 2010. Falling under COMAC, the National Office for Accreditation (SEMAC) is responsible for implementing a quality management system in line with national and international standards. SEMAC is engaged with various regional and international accreditation organisations, such as an associate (but not signatory) member of the ILAC and a full member of the Arab Accreditation Cooperation (ARAC) (ILAC, n.d.). SEMAC is also a member of the IAF, although not a signatory of the multilateral recognition arrangements.[63] SEMAC is currently accrediting testing and research laboratories, calibration laboratories, medical laboratories and certification bodies. The accreditation system in Morocco suffers from several shortcomings and therefore receives relatively low recognition (Interview with TÜV Maroc, November 2018; Interview with IMANOR, November 2018; Interview with IRESEN, November 2018). Specifically, the accreditation of laboratories is not systematically recognised by other government departments (OECD, 2018). In addition, not all certification bodies are accredited, which leads to lower service quality for the private sector (OECD, 2018). Furthermore, only few laboratories are accredited, which creates hurdles for domestic producers as they cannot export their products tested using locally accredited labs and instead have to rely on international services, which adds to their costs.

Lastly, SEMAC's accreditation is not yet recognised by the IAF, which creates a major challenge and is the reason why many certification bodies and laboratories are not accredited, especially those servicing new activities/sectors (Interview with TÜV Maroc, November 2018). To become internationally recognised, SEMAC has to become more independent from the Ministry of Industry with regards to budget planning. Independence is

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62 Technical regulations can, however, also be misused to artificially generate income for the labs, which are politically well-connected, as has occurred in Ethiopia (see Section 5.3).

63 SEMAC has not yet been admitted to the IAF multilateral recognition arrangement, but it is "on probation until 31 March 2019 for non-fulfilment of voting obligations" (IAF, n.d.).

a precondition for the recognition by ILAC. Lack of independence from the Ministry of Industry also creates a conflict of interest with the National Institute for Standards (IMANOR) (see below), which would contradict ISO 17011 that forms the basis for the multilateral recognition arrangement. These shortcomings of SEMAC and its implications (as discussed above) pose major hurdles for the effectiveness of the Moroccan NQI system.

Completing the international recognition of an accreditation body normally takes at least five to seven years (Kellermann, 2019). In the case of Morocco, since SEMAC already conducts accreditations and follows ISO/IEC 17011, that timeline should be shorter. Meanwhile "twinning agreements" (Kellermann, 2019) could be considered for SEMAC to prevent blocking opportunities for local stakeholders that seek accreditation of their certification activities (see the renewable energy section).[64,65]

IMANOR is the national organisation responsible for developing national standards, certification of products and of management processes, dissemination of information referring to standards, education and training in this area, and cooperation with international and regional peer organisations. Established in the 1960s, IMANOR was reformed in 2014, resulting in a higher level of independence and financial autonomy. IMANOR is a member of international and regional organisations including ISO, International Electrotechnical Commission (IEC), the European Committee for Electrotechnical Standardization (CENELEC) and Standards and Metrology Institute for Islamic Countries (SMIIC). IMANOR's department for standards has four divisions: (1) energy, water and sustainable development; (2) construction, materials and capital goods; (3) consumer goods and services; and (4) dissemination of information on standards. IMANOR is the only actor responsible for certification of products, while for system management certification there are other private

64 As mentioned in Kellermann (2019), until national accreditation bodies gain international recognition, they can "enter 'twinning agreements' with an accredited body already internationally recognized. This arrangement will help the newly established accreditation body gain necessary experience for the peer review as clients may be issued with a joint accreditation certificate" (p. 226). Further, "the twinning partner does not only provide information on proven systems, but also supports operations in a meaningful way. ... This … helps the newly established accreditation body gain practical experience and a track report before it is peer reviewed for international recognition" (p. 193).

65 Information could not be found on whether such twinning agreements have already been initiated or considered by the SEMAC.

(national and international) actors in Morocco. Training of auditors and certification of installers has also been a key activity since 2012, but these professionals have not yet been active in this area mostly because of a lack of capacity (resources and competences). As the only body responsible for standards in Morocco, IMANOR has adopted a large number of standards in various sectors, including the renewable energy sector, energy efficiency and sustainability. Their activities are driven by demand from the private sector. Therefore, as the green economy expands nationally, they expect to increase their work in these sectors. However, some of the interviewees argued that the link between IMANOR and the private sector remains weak and mechanisms for increasing demand for standards are not yet institutionalised (e.g., information, awareness campaigns). Instead, IMANOR's activities are currently primarily driven by government and public demand, which goes against the character of a well-functioning NQI system. It is true that the green economy agenda is highly government driven (through national and sectoral strategies, targets and road maps), but without the engagement of the private sector in these new green sectors, IMANOR's services have limited value. The General Confederation of Moroccan Enterprises (CGEM) has become increasingly engaged in bringing the green economy objective to the private sector (as discussed later) and perhaps they can also play a role in stimulating demand for standards related to green technology sectors.

Further, our interviews also suggest that information on existing national standards remains opaque for those interested in investing in Morocco, requiring time and effort to know which standards exist and apply.[66] Therefore, an optimisation of IMANOR would be needed. In sectors that are more established, such as the automotive, the industry association assists the private sector and potential investors with such information, but emerging sectors/activities related to the green economy suffer more from these shortcomings.

Conformity assessment (testing, certification and inspection) is carried out by several stakeholders. The National Laboratory for Trials and Studies (LPEE) is the largest public organisation responsible for verification and research, but also for testing and inspection. Its financing, ensured through both public

66 For instance, on IMANOR's website one can get a list of standards that have been adopted or developed nationally in the form of an 812-page PDF document that is not easily searchable and the information is presented only in French. A search in the database can be made online, but the results give you only the name of standard without details of its content. Inquiries can be made online, but it takes time to receive the information.

and private funding sources,[67] remains difficult to ensure (for example, for upgrading their equipment and expanding their activities in emerging sectors such as green economy). LPEE has several regional technical centres and several technical and scientific centres in various sectors. For instance, in the environmental sector there is the Center for Studies and Research on the Environment and Pollution (CEREP), which works in the areas of water, air, soils, and solid waste. LPEE is also active in other green economy areas, such as energy efficiency in buildings, recycling of building materials (including roads), and energy efficiency in industrial processes, but it is not accredited in all areas. Other core challenges for LPEE are to sensitise the private sector on quality aspects and to "lobby" for technical regulations and their implementation.

Private laboratories are of course also present in Morocco but not all are accredited (Interview with TÜV Maroc, November 2018).[68] A total of 83 accredited laboratories (LPEE included) for all sectors (e.g., textiles, chemicals, water, mining, construction materials and agriculture) are listed on the Ministry of Industry's webpage. Another relevant national laboratory for air, water and waste is the National Laboratory for Pollution Assessment and Monitoring (LNESP). Environmental pollution is also covered by several other laboratories that offer services for the agriculture sector (such as the GAYA, LABOSFORT and LC2A laboratories). In the water sector, the national utility company ONEE also offers quality testing services through its Department for Water Quality Assurance (DCEM) (as well as its regional offices). Furthermore, LYDEC, the private water provider also has an accredited laboratory (Labelma). Several other laboratories, both public and private, exist.

Certification is also carried out through public and private actors. IMANOR, as discussed above, is active in the certification of products, management systems and auditors. Private actors such as TÜV Maroc or BureauVeritas, among others, also provide certification (for management systems and auditors), inspections and audits in various sectors, including energy, environment and agriculture.

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67 Moreover, about 10 per cent of their revenues are reinvested every year in renewing and upgrading their equipment and facilities (LPEE, n.d.).

68 In this interview, we also learned that it is not easy to find information on which laboratory can perform what kind of services in particular sectors. It takes time and resources to find the right information.

For metrology, the National Metrology Laboratory (LNM), part of LPEE, is the main public actor designated by the Ministry of Industry and accredited by SEMAC. Metrology services are offered in the areas of work in which LPEE is active (related to equipment calibration and setting and related training), specifically for the industrial sector, construction, environment and hydraulics. LNM is accredited by SEMAC for the quantities of density mass, volume, time/frequency and length and for the sizes of mass, force and torques, pressure, electricity (including electricity meters), temperature and humidity. One major challenge in the metrology area is that there are no other designated labs and several other quantities are not covered by LNM (such as time and frequency, chemistry and biology, photometry and radiometry, accoustics and vibration) (Personal communication with PTB staff, January 2019).

LNM participates and is part of various international and regional bodies, such as the North African Metrology Network (MAGMET) and the Intra-Africa Metrology System (AFRIMETS). LNM offers primarily secondary calibration services for the private sector, but also primary calibration services.[69] Other metrology laboratories also exist in Morocco, which serve sectors such as electronics, automotive and aeronautics. A total of 21 metrology laboratories are listed on the Ministry of Industry's website as being accredited. The Moroccan Laboratory for Industrial Metrology (L2MI) is one of those metrology labs that also offers services related to air quality and other measures that might be relevant for green technologies, along with, for instance, Lydec's Technical Centre for Metrology (CTM) and the National Office of Drinking Water's (ONEE) research department of the DCEM for water-related technologies.

Other actors like universities and research and training organisations also play a role in developing capabilities and expertise related to QI in cooperation with testing labs, enterprises and the public sector. Universities with a strong focus on renewable energy, water and the environment, such as the Rabat School of Mines (ENIM), could be important in educating future engineers on the relevance of QI and the various system components. ENIM has testing and research labs in some areas (battery storage, co-generation, water treatment, transport, thermal insulation, air conditioning and energy

69 From their website, it is clear that LNM offers primary calibration services to several laboratories, for services such as water quality assurance, but it is not clear whether they do so for other sectors/activities (LPEE, n.d.).

efficiency in industrial processes), thereby contributing to the NQI system. For instance, just recently, ENIM signed a project agreement with the French Development Agency (AFD) for research and testing facilities on environmental analytics tools for air pollution, which also includes funds to establish curricula in this field (Interview with ENIM, November 2018). Their work on QI, however, is currently limited to the impact of standards related to energy management and safety. Another relevant example is the cooperation between the Mohammed VI Polytechnic University and the Research Institute for Solar Energy and New Energy Technologies (IRESEN) in the development of the Green Energy Park, a research, testing and certification platform for solar energy technologies (see Section 5.5.2 for more detail). Cooperation between universities and national conformity assessment actors, such as LPEE, is apparently non-existent, which, for the above reasons, we consider to be a weakness.

The demand for QI services should come from the private sector (i.e., enterprises) and from consumers, driven either by standards, competitive pressures or consumer preferences (e.g., related to environmental quality and performance). As highlighted earlier, however, demand for QI from the private sector is currently weak in Morocco. Therefore, awareness of QI plays an important role in increasing demand for related services. In the past, weak quality performance of SWHs has reduced the market for these products in Morocco (UNDP, 2011), lowering trust and hurting the prospects for future deployment. Promoting the importance of quality, however, is essential as certification (for example), even if conducted, is oftentimes not mandatory unless driven by technical regulation. Moreover, as the market for green technologies increases and opportunities for the export of products and services emerge, an increase in competitiveness will be increasingly in focus for the private sector. For this reason, QI services will become even more important.

Quality promotion is currently primarily carried out by a non-governmental actor, the Moroccan Union for Quality (UMAQ), which was created in 1999. UMAQ organises a National Quality Week once a year to promote the relevance of quality assurance in different sectors at local, regional and national levels. QI actors support this initiative/information campaign with their participation, but UMAQ does not play a strategic role as such. Following this event UMAQ publishes an assessment of the main opportunities and challenges facing the NQI system in Morocco, but it is not sure to what extent their actions provide input to strategic bodies like the CSNCA. UMAQ also organises a National Prize for Quality (for large enterprises and for SMEs) with the support of the Ministry of Industry, although, to our knowledge, the last time such an event was organised was in 2016.

5.2.2 Renewable energy systems – focus on solar energy

As Morocco imports between 90 and 95 per cent of its energy needs and its energy consumption is expected to increase by an average of between 6 and 8 per cent per year until 2030 (IEA, 2016), renewable energy has been a national priority to improve its energy security and reduce its vulnerability to fluctuations in world oil prices.[70] A central component of Morocco's National Energy Strategy has been the renewable energy target of 42 per cent by 2020, later extended to 52 per cent by 2030 (accounting for 6,000 megawatts (MW)). Hydropower is also included in these targets, but solar and wind energy are the primary focus.[71] Various electricity generation projects that have already been implemented, or are in the development stage, are expected to certainly meet (and even exceed, as in the case of wind energy) the set targets of 2,000 MW for solar and 2,000 MW for wind energy by 2020.[72] These developments will also put Morocco in a good position to achieve its targets by 2030.

Despite the large potential that wind energy and hydropower offer, we focus this short analysis on solar energy, in particular solar PV, for several reasons. As per our interviews, new sites for wind energy projects are not likely to be approved in the coming years, slowing down market development in this sector. As most wind energy projects are developed with international consortia of firms, the needs for nationally provided QI services are expected to remain low.[73] Because CSP technology is more complex and concentrated

70 Morocco is the largest energy importer in North Africa (Chentouf & Allouch, 2018).

71 The technical potential for both solar and wind is high: 10,829 MW for solar and 25,000 MW for wind (Chentouf & Allouch, 2018).

72 In 2015, Morocco had a production capacity of 8,154 MW, this is expected to be increased by 6,500 MW by 2020. Of this, approximately 14,500 MW capacity, solar and wind will contribute 4,000 MW, which represents a 28 per cent share in total production capacity (International Trade Administration, n.d.).

73 A tower and blades manufacturing facility is being built by Siemens in Tangier, which means that national QI services might become relevant, especially if Morocco is seeking export markets (Siemens, n.d.). Therefore, it would make sense to keep an eye on developments in this sector.

on a few players in Europe and North America, "users" of this technology in Morocco will continue to rely on QI services from international providers (see MASEN interview). Lastly, hydropower (large and small) is a technology for which domestic capabilities are already high in Morocco.

The solar energy technologies of interest for Morocco are solar PV and CSP. Morocco's engagement with solar PV technologies has been significantly intensified since IRESEN was established. IRESEN has been active in establishing an R&D platform for solar PV as well as in developing training and education programmes in this sector. IRESEN created the Green Energy Park (GEP), with the support of the Ministry of Energy, Mines, Water and Environment and the Office Chérifien des Phosphates (OCP) Group (inaugurated in 2017), to serve as a state of the art research centre, training platform and testing facility for solar PV technologies.[74] By now, they have tested almost 100 per cent of all existing types of solar PV modules in the Moroccan climate (humidity, UV ray intensity, temperature, etc.), they have characterised the modules and they have assessed their impact on the environment. Their testing activities are not limited to modules, but include testing of other system components, such as battery storage and inverters,[75] with the goal of adapting existing technologies to local environmental conditions. To do that, IRESEN set up its own testing and research laboratories and has developed several international cooperation programmes in Europe, Asia and North America. Given this set of activities, IRESEN has also started working on aspects related to QI, in particular with respect to the development and adoption of standards (in cooperation with IMANOR). Given their extensive testing facilities, IRESEN hopes to be able to certify their solar PV testing facilities and processes. Yet, because of the limitations associated with SEMAC not being internationally recognised, the accreditation process for their testing facilities has been significantly delayed.

As the price for PV modules continues to decline, several interviewees argued that off-grid PV systems will be increasingly deployed in Morocco. This calls for a wider use of battery storage technologies and associated QI services. Another related technology area that becomes increasingly

74 GEP is also expanding their activities into Africa, by developing a PV testing facility in the Ivory Coast.

75 They do not do testing on inverters. They have some projects on "adapted inverters" but not on the characterisation of inverters.

important for Morocco, as the share of renewables in electricity generation increases, is smart grids (Sahbani et al., 2016). Here, however, partnership with European organisations is key, because at present Morocco has low capabilities in this sector.

Moreover, manufacturing of solar PV, although currently limited, shows potential, especially if export markets in Sub-Saharan Africa are considered. There are two domestic producers of PV modules: Almaden, which manufactures ultra-thin, high-efficiency, double-glass PV modules that are much better adapted to local climate conditions than others[76]; and PV Industry, which manufactures first generation PV modules (Interview with IRESEN, November 2018). Presently, their production volume remains low so it is still economical for them to use QI services abroad. However, as their production scale increases, national QI services, especially related to conformity assessment and metrology, will become more important.

The Moroccan Agency for Sustainable Energy (MASEN), a large national developer of CSP projects in Morocco and that is increasingly active in the PV sector, has expressed strong interest in building up the QI for solar PV technologies. Specifically, as several solar power plants are already operational, they see the need to optimise solar sites for future power plants. For this purpose, metrology services, which are currently limited in this area, are needed. Also, MASEN plans to further develop the medium voltage and decentralised solar energy market, which also calls for QI services to upgrade quality of products and systems and the knowledge of workers in terms of quality management. Given the scale of their operations, MASEN can make a strong impact at the system level.

Nevertheless, a main problem seems to be the low cooperation and coordination between MASEN and IRESEN, which might hinder efforts to build the necessary QI for solar PV or reduce the effectiveness of related investments.[77] Until recently, the market segment for these two organisations (with respect to R&D and capacity building) were fairly clear, that is, MASEN focussed on large-scale project development while IRESEN focussed on R&D, training and capacity building for solar PV and related technologies. Now MASEN is seeking to develop capabilities for testing and

76 In our interview, IRESEN mentioned that this is supposedly the largest and most modern solar PV manufacturing facility in Africa.

77 This is an older problem, mostly related to the agenda of specific people and at times politics, documented in Vidican (2015) and Vidican et al. (2013).

characterisation of PV modules, capabilities that have already been acquired by IRESEN (as discussed above). Without sufficient cooperation and coordination between the two stakeholders, the scale of MASEN's projects and their large investment capacity could undermine IRESEN's efforts.

Another area with significant untapped potential is the market for solar water pumping and SWHs. In this market for small-scale installations, strong focus is placed on upgrading the quality of installations (e.g., training and certification for installers) and increasing domestic capabilities for producing local components (e.g., solar water pumps).[78] A label for the certification of solar PV installers for different installation sizes (taqa pro PV and taqa pro PV+) and for solar water pumps (*taqa pro Pompage Solaire*) was launched in 2018 with support of German development cooperation (taqa pro, n.d.). However, while the demand for these services is very high, current programmes remain limited. Therefore, these efforts should be supported for scale-up.

The market for solar energy is taking off in Morocco and is expected to grow in the coming decades. Low cost, advantageous conditions (i.e., solar insolation), as well as the general need for and commitment to diversification of energy sources will contribute to these developments. Several standards have been already adopted (especially for solar PV, solar thermal and solar water heaters). Testing and certification activities are already underway, although capacity remains limited and efforts are slowed by previously the described NQI system-level challenges.

5.2.3 Energy efficiency in buildings

Given the concerns for energy security and increasing energy demand, energy efficiency has also been a priority in the 2009 National Energy Strategy, which specifies a target of reducing energy consumption by 12 per cent by 2020 and by 15 per cent by 2030 (AMEE, n.d.). Law 47-09, the "Law on Energy Efficiency", was enacted in 2011 and addressed different measures for increasing efficiency of energy consumption and reducing energy costs in buildings and construction, transportation and industrial processes (sectors that represent 90 per cent of Morocco's energy consumption). Energy consumption in the industry grew by more than 40 per cent in the past

78 UNDP also has a project on solar water pumps (focussed on certification of products and installers), but we did not find much information on this programme during our fieldwork.

decade, and the residential sector experienced approximately 24 per cent growth in final energy consumption over the same period. The majority of this increase can be attributed both to a strong deployment of household appliances (which have now become available to the vast majority of the population) and to the poor efficiency of the household appliances sold on the Moroccan market.[79]

Law 47-09 introduced a range of measures such as mandatory energy audits (specifically for energy intensive sectors), minimum energy performance standards for appliances and preferential tariffs ("super-peak" tariffs) for industries that voluntarily shift their energy consumption away from peak periods, as well as energy efficiency public procurement requirements. The Energy Efficiency Code for Buildings elaborated following this law has a strict focus on building envelopes, thermal insulation, and equipment (such as heating and cooling, SWHs, lighting and solar PV on rooftops). Also, in 2011, the Moroccan Standard NM 14.2.300 was made mandatory (it was initially introduced as a voluntary measure in 2010), requiring mandatory labelling for cooling appliances, cooking appliances, cleaning appliances and household electric lamps.

In 2016, mandatory thermal regulation standards were applied for the construction sector (e.g., for building envelopes aimed at reducing consumption and improving comfort) as well as energy system audits for existing buildings.[80] These regulations have already led to market creation for such services and materials (such as local materials for insulation, for example, husk, clay, mix of soil and dates, and glazing materials) and an increasing demand for the training and certification of experts, such as auditors, construction engineers and technicians (Interview with the Moroccan Agency for Energy Efficiency (AMEE), November 2018).[81] Although currently most materials (the conventional ones) for thermal insulation are imported, LPEE claims to already have capabilities and interest in expanding their activities in conformity assessment for local materials (Interview with LPEE, November 2018). AMEE estimates that the mandatory thermal regulation standards will reduce heat and air

79 Energy consumption in the transport sector has also increased significantly since 2004.

80 In 2010, such regulations were introduced on a voluntary basis.

81 Currently, all products for thermal insulation are imported because they are not produced domestically. The expectation is that once the market picks up, local production will become appealing to investors.

conditioning needs in buildings by 39-64 per cent for the residential sector and by 32-72 per cent for businesses (Oxford Business Group, 2015).

There are testing laboratories for construction materials such as the LPEE and the Center for Building Techniques and Materials (CETEMCO). In addition, two national universities have capabilities to carry out such tests: Ecole Supérieure de Technologie in Salé and Cadi Ayyad University in Marrakesh (Interview with AMEE, November 2018). However, as stressed in our interview, more investment is needed into building capabilities for laboratories focussed on characterising construction materials (in terms of conductivity, resistance, thermo-physical characteristics, etc.). The current practice is to send materials to different labs in France. However, with higher demand, this will no longer be feasible.

The reform of fossil-fuel subsidies especially since 2014 (with the objective of eliminating all subsidies except that of liquid petroleum gas by 2018) has also contributed to improving the market for energy efficiency measures and products (Vidican Auktor & Loewe, forthcoming). In addition, a new law is currently under preparation that refers to minimal performance of buildings, with a focus on system-level aspects, such as air conditioning, labels for products and appliances and so on (Interview with AMEE, November 2018).

Given this recent change in the legislation, AMEE has been highly focussed on working with vocational training centres to develop new training programmes (from architects and construction engineers to energy management in local communes and municipalities) and certification programmes. The Ministry of Energy (MEMEE) is also currently conducting a needs assessment study along the value chain of energy efficiency with regard to, for instance, insulation materials and mineral resources.

AMEE, through their Green Labelling programme, is also active in developing labels and certification schemes for energy efficiency equipment and electric appliances. A label already exists for energy efficient buildings, but, according to our interviews, it is not sufficiently or effectively marketed.

Another technology of interest in Morocco is small-scale solar thermal technologies (i.e., SWHs). The programme for the SWHs market development in Morocco (PROMASOL) programme implemented between 2002 and 2010 contributed to increasing the number of companies that assemble and import these technologies (Allali, 2011). Standards and a labelling programme already exist,[82] as well as training and certification of installers. The current generation capacity of SWHs in Morocco is between 455,000 and 640,000 m^2,[83] with a target of 3,000,000 m^2 by 2030 (IEA, 2016, p. 32). The follow-up incentive programme for PROMASOL is Shemsi[84], which aims to increase deployment of this technology and enable local manufacturing of parts and components. The AMEE's Shemsi programme aims to install 1.7 million m^2 of SWHs by 2020 by providing certification and labelling of SWHs, training and accreditation of installers of the renewable energy industry association (AMISOLE) (AMEE, n.d.), technical skills training, funding, awareness building and integration of SWHs into building planning codes (Kingdom of Morocco, 2014). However, presently, the Shemsi programme is considered ineffective (Chaudier, 26 April 2017). Insufficient financial support and the persistence of liquid petroleum gas (butane gas) subsidies are among the factors that constrain the market for this technology in Morocco.

These developments and trends suggest that the market for energy efficiency in buildings (and in other sectors) is expected to increase in the coming decades. As standards are made mandatory and enforcement mechanisms are implemented, the private sector will demand related services and products, as well as QI services. Since this is a relatively new sector for Morocco and domestic capabilities exist, supported by increasingly strict regulation, additional investments in QI would be justified, as discussed in Section 5.2.7.

5.2.4 Solid waste management

With a fast increase in the rate of urbanisation, levels of consumption and industrial development, Morocco faces solid waste management challenges. On average, 5.8 million tonnes of municipal solid waste are generated per year, and that amount is projected to reach 6.2 million by

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82 A quality label for SWHs commonly known as the "macaron" was designed to prove compliance of SWHs with quality standards (Allali, 2011, p. 7).

83 For SWHs, the collector surface area is often used as a proxy measure of generation capacity.

84 Not to be confused with the RECREEE programme, Solar Heating Arab Mark and Certification Initiative (SHAMCI). Inspired by the European certification scheme Solar Keymark, SHAMCI is a certification scheme for solar thermal products and services that promotes the adoption of standard quality measures, accreditation schemes and quality labels across the Arab region.

2020 (World Bank, 2016b). The cost of environmental degradation due to solid waste was estimated at 0.5 per cent of GDP (World Bank, 2016b). Two national strategies govern action in this sector: the National Solid Waste Management Programme (PNDM) 2008-2022, developed with the World Bank's support in three phases, and the National Master Plan for Hazardous Waste Management supported by German development cooperation. Based on our interviews, a ministerial committee is currently conducting a needs assessment on the issue of solid waste management, with an emphasis on value creation from recycled materials.[85]

The PNDM covers the entire value chain for solid waste, from collection to treatment. Since the start of the programme, 20 landfills have been established, 11 controlled landfills are being developed and another 10 are in planning. Further, 26 uncontrolled dumps have been remediated and 174 are scheduled for remediation. The objectives of the PNDM are to achieve a 90 per cent collection rate by 2020 and a 100 per cent rate by 2030, to rehabilitate or close all existing disposal sites by 2020, to develop the sorting-recycling-recovery chain with pilot sorting projects to reach a recycling rate of 20 per cent by 2020, to expand and implement solid waste management plans for household and similar waste for all prefectures and provinces, and to train and increase awareness among all stakeholders.

An important part of the national effort is focussed on value addition through recycling, composting and production of energy. However, even if composting and energy generation have high potential in Morocco, our interviews suggest that weak progress has been made in these areas, either for cost reasons, or because of a lack of technology acceptance (e.g., composting or anaerobic digestors).

Following the adoption of the "extended producer responsibility" principle included in the National Charter for the Environment and Sustainable Development published in 2014, several products were targeted: plastics, batteries, tires, motor oils and food oils (Oxford Business Group, 2018). So called "green taxes" (basically product taxes) are already applied for

85 Unfortunately, we could not get more information or material on this effort.

plastics,[86] which has enabled the creation of a recycling value chain (World Bank, 2016b). Efforts are currently underway to establish other value chains for electronic waste, used tires, waste oils, paper and building materials (i.e., demolition waste) (see World Bank (2016b) and various interviews, for example, the ENIM and LPEE interviews). However, there are standards related to the recycling of these materials that are currently lacking and would need to be adopted by IMANOR.[87]

Despite the increasing number of waste valorisation initiatives, just 26 per cent of recycled products are derived from landfill waste (Oxford Business Group, 2018). Rates of recovery for scrap metal and glass are high (reaching 100 per cent and 92 per cent, respectively) but are lower for paper and cardboard (18 per cent) and plastic (8 per cent) (Oxford Business Group, 2018). The local subsidiary of the French company Pizzorno Environnement, TEODEM at Oum Azza, is currently the largest centre for recycling and valorisation of solid waste (paper, plastic and metal) in North Africa. TEODEM is certified with the ISO 14001 standard. Other private sector initiatives are also underway, such as the French cement company Lafarge Holchim, which invested EUR 5.1 million in a sorting centre and processing centre to produce alternative fuel that would power a cement and clinker production unit (Oxford Business Group, 2018).

Industrial waste is also increasingly targeted and has been included in the Integrated Industrial Platforms programmes part of the industrial development strategy (Hahn & Vidican Auktor, 2018). CGEM joined the Ministries of Energy, Industry, and Interior to create the Coalition for Waste Valorization (Hahn & Vidican Auktor, 2018) to strengthen the legal framework, develop waste chains and waste-management services, as well as train and raise awareness. Morocco generates 1.6 million tonnes of industrial waste per year, of which 22 per cent is hazardous (Oxford Business Group, 2018). In 2018, a major study was commissioned on mining waste (from more than 1,000 mining units in Morocco), which is a major problem, especially given the large impacts on the pollution of soil, water

86 The revenues generated by the tax (EUR 18.5 million in 2014 alone, according to the Oxford Business Group (2018)) are to be reinjected into the environmental sector through the National Environmental Fund in the areas of recycling and treatment of waste (Green Fiscal Policy Network, 2017). To date, however, these funds have not been used and the planned agreement to establish a plastics valorisation ecosystem has not yet been signed (Oxford Business Group, 2018).

87 Unfortunately, we did not get more detail on this point.

and human health (see interview with ENIM). The major focus is on the characterisation of materials, treatment (chemical, physical, biological) assessment of environmental impacts, and solutions for rehabilitation of affected areas (Zerrour, 5 April 2018). A major problem here, as specified in our interviews, is that there are no regulations with regards to management and rehabilitation of polluted sites.

Recycling of building materials has been repeatedly mentioned in our interviews as an area of high potential for Morocco. In particular, recycling of roads (large parts of road infrastructure are being rebuilt and extended) but also recycling of building materials (such as wood, cement, gypsum and PVC). In this area, however, there is a lack of standards (e.g., for what kind of materials should be removed from the building before demolition),[88] certification schemes,[89] and technical regulations for quality assurance. IMANOR should work more intensively in this area, but they lack direction (which would be provided by mandatory technical regulations and strategic focus).[90] A needs assessment would be necessary to identify specific gaps in the QI in relation to recycling of building materials.

5.2.5 Sustainable transportation

The highest increase in energy consumption in Morocco has been in the transport sector; it grew by 81 per cent between 2004 and 2014, an AAGR of 5 per cent. Most of this increase can be explained by significant growth in the vehicle fleet, the majority of which are diesel vehicles. Therefore, transportation is also a key sector for enabling the transition to a green economy in Morocco.

Aside from renewing the automobile fleet and imposing stricter emission standards, a core focus of the national transport policy is on promoting e-mobility and inter-modal transportation through the following actions:

88 See the example of the Austrian standard ÖNORM B3151 (European Commission, 2016, p. 33).

89 An example here is the Dutch certification scheme for demolition processes, a voluntary instrument to encourage quality demolition processes (European Commission, 2016, p. 33).

90 In Bulgaria, for example, "the contracting entity in public procurement for design and construction works by law has to include a requirement for the use of recycled building materials in contractor selection criteria and work contracts" (European Commission, 2016, p. 17).

(1) defining a plan to promote e-mobility by mode and user groups (initial priority for electric buses and government actors); (2) setting an e-mobility target for the state fleet (at least 10 per cent by 2030, although other sources point to 100 per cent) of two-wheelers; (3) integrating "low/zero emission" requirements into public procurement; and (4) defining a degressive subsidy for the acquisition of EVs for local authorities and group purchases (Industrie du Maroc Magazine, 5 December 2018). Moreover, in November 2018, the Ministry of Industry launched a commission to examine regulatory tools for reducing emissions in the transportation sector (Interview with CESE, November 2018).

Since the UNFCCC's Conference of the Parties 22 (COP22) in 2016, two lines of public buses in Marrakesh have been changed to electric buses and some pilot e-cars have been set in use for government entities. Because the King's speech in 2018 stressed the goal of having 10 per cent of the Moroccan (public sector) fleet as electric autos within 10 years, important developments are expected in this area in the next few years (Interview with IRESEN, November 2018).[91] The goal is to start by transitioning the fleet of cars in the public sector to e-vehicles and building a solar PV charging station infrastructure. Combining charging stations with renewable energy comes in focus (as suggested by IRESEN's research activities) and calls for studies on grid impact and increasing the need for smart meters.

Renault, Peugeot and Tesla have already expressed concrete interest in investing in this sector (Interview with the Ministry of Industry, November 2018). BYD, a Chinese car company, has also committed to a EUR 500 million investment in a manufacturing plant in Tangier that will produce electric batteries, e-cars, and e-buses; in principle, BYD has expressed interest in building an ecosystem for e-mobility in Morocco (Industrie du Maroc Magazine, 5 December 2018). A key advantage for manufacturing batteries in Morocco also relates to the country's cobalt reserves. While Morocco's reserves are smaller (Morocco is the 12th largest exporter of cobalt) battery manufacturers are increasingly shifting their cobalt imports away from the Democratic Republic of Congo (currently the largest exporter) to Morocco due to "unregulated, unauthorised and unsafe mining of cobalt" in Congo (Petavratzi, Gunn, & Kresse, 2019).[92] MANAGEM, the national mining

91 In September 2018, an international Green Mobility Forum was organised in Marrakesh to examine challenges and opportunities for this sector in Morocco.

92 For example, starting in 2020, BMW will import cobalt from Morocco instead of Congo (Petavratzi et al., 2019).

company, is working to increase their exploitation and produce electric cathodes, which would then be sent to China to be processed into electric cells (they could not be produced in Morocco due to high capital costs; they are currently produced only in China, in Nevada by Panasonic, and in Hungary with high state subsidies) and then brought back to Morocco to be integrated into electric batteries (Petavratzi, Gunn, & Kresse, 2019). Another example of a local mobility project is the agreement signed in October 2017 between the City of Marrakesh, AAQIUS (a company that develops disruptive projects for green mobility) and IRESEN to transform Marrakesh region into a "zero-carbon" mobility territory (AAQIUS, 5 October 2017).

Several regulatory aspects must be considered. For instance, all new electric and hybrid technologies are exempt from customs duties and taxes. However, other supportive regulations are missing, for example, regarding air pollution and emission measurement and upgrading the fleet of taxis.

The QI necessary to support the development of e-mobility in Morocco is currently weak. However, given the overall commitment to shift to a green economy, and given the air pollution problem that Morocco is facing, large potential exists to upgrade the QI in this area, especially if local manufacturing of parts and components for e-mobility is envisioned for the medium- and long-term.

5.2.6 Water management

Morocco is a country with extreme water stress. Therefore, this sector is of high relevance on the national agenda and is also part of the NDCs. It is, furthermore, considered critical for the transition to a green economy. Overexploitation of water resources and the degradation of existing resources (i.e., the water table) are some of the most pressing issues. Therefore, water management measures, such as reducing consumption, identifying new water sources (i.e., desalination), building of dams (14 are under development and 35 are planned), and water treatment (to reuse 325 million m^3 of grey water) are considered priority interventions (La Nouvelle Tribune, 14 November 2017). Aside from increasing access to potable water to 100 per cent by 2030, the National Program for Treatment and Purification of Wastewater seeks to achieve a 60 per cent volume of treated wastewater. In the agricultural sector, *Plan Maroc Vert* also examines the use of different technologies for irrigation (such as drip irrigation) to reduce water consumption by 3.2 billion m^3 by 2030 (La Nouvelle Tribune, 14 November 2017).

A National Water Plan is currently under preparation and aims to reduce water demand by 120 million m^3 by 2025, using water metering, for instance (La Nouvelle Tribune, 14 November 2017); treat wastewater; and identify new sources of water. A Water Law was adopted in 1995 (Law 10-95) based on which, for example, water pollution fees have been charged on dumping, discharge and disposal of effluents into surface and groundwater. Nevertheless, as is the case in other sectors, enforcement of regulations remains weak.

Water desalination, as part of Morocco's effort to exploit "non-conventional" sources of water, has a high national priority. Desalination (using reverse osmosis technology) is not new for Morocco; current efforts, however, target solar and wind energy technologies, given the high energy intensity of the desalination process. The National Water Plan identifies a capacity of 500 billion m^3 for water desalination for a total cost of USD 3 billion to be used for supplementing access to potable water and irrigation. Such projects are piloted by the Ministry of Agriculture and developed as public-private partnerships. Companies, such as Nareva, the national leader in wind energy project development (and more recently also solar energy), are highly involved in strategic discussions with policy makers (see interview with Nareva). One desalination plant at Dakhla intends to provide water for irrigation and is currently under development. Chinese investors are also active in this sector and are committed to constructing three dams and two seawater desalination plants per year over a period of time (Chaoui, 29 June 2018). However, in this area, NQI has not been considered highly necessary (as per our Delphi survey), rather, domestic capabilities are necessary for operation and maintenance. Yet, this remains debatable.

Water treatment and grey-water reuse systems have also been identified as strategic technologies, but as they are highly capital intensive and most technologies are imported, little exists in terms of domestic QI capabilities. The same is true for desalination plants. Maintenance is also an issue. Water testing laboratories do exist at the national level, such as ONEE's Analysis Department of the DCEM, the LNESP, Labelma (Lydec's laboratory for water analysis), and LPEE's CEREP.[93] OCP, the national phosphates company, has some testing capacities (as they need treatment capabilities for their own operations), but they do not sufficiently meet existing (and projected)

93 LPEE has activities related to water pumping, distribution and assessing distribution losses.

demand. Major disconnect is seen in this sector between the private sector, the public sector, research labs and conformity assessment actors.

5.2.7 Overall implications for NQI interventions

At the system level, an NQI strategy (or road map) for the green sector would be necessary to align necessary QI actions (e.g., standards adoption and development, investment for testing laboratories, metrology and training) with the national and sectoral strategies. This would ensure synergy between actors and coordinate activities at the national and sectoral levels. For example, LPEE argues that without a road map highlighting the QI interventions necessary to achieve the set "green" targets, the laboratory finds it difficult to plan investments in new equipment, while the private sector, on the other hand, does not see a need for such services. Such a strategy would call for QI needs assessments for different sectors, the results of which would then signal to the specific NQI actors (related to, for instance, standards, conformity assessment, metrology and certification) which types of interventions they should consider. A systematic and detailed needs assessment with regard to QI for the green sectors was proposed in 2014, but it has not yet been performed. Such studies have been conducted for other sectors, such as textiles and leather and automotive. This points to the still early progression towards a green economy and to the large potential and need for action in this area. To this end, strengthening the role envisioned for the CSNCS is essential for ensuring coherence between QI-related measures and sectoral strategies. Also, supporting awareness-raising activities in the private sector and in the society at large, through initiatives such as those of UMAQ and through business associations or NGOs, could contribute to increasing demand for QI services.[94]

At the QI element level, several interventions could be considered. Regarding standards, a major weakness we identified, as mentioned above, relates to the communication and dissemination of information. The WTO's Technical Barriers to Trade Agreement requires parties to maintain an enquiry point to answer questions on technical regulations and standards developed by government entities. Often, however, as the case of IMANOR shows, these inquiry points do not function well. Technical assistance may be offered

94 Consumers find on the market both approved and fake labels for organic products (Interview with IMANOR, November 2018).

to improve communication of standards and dissemination of information through a "one-stop shop" office for both Moroccan and foreign firms seeking information on various standards.

For accreditation, support with obtaining international recognition of SEMAC through, for instance, twinning arrangements, could speed up certification initiatives and accreditation of new labs seeking to engage in the green economy (see Chapter 3). On conformity assessment, improving the system-level gaps, as discussed above, could support stakeholders in expanding their work or engaging with new sectors. More specifically, funding for testing equipment and for developing training and certification programmes could help build capacity in existing organisations. Yet, it should be ensured that no duplication of expensive equipment is financed by international sources and that a reasonable demand is secured by testing facilities. For metrology, funding could also be important for upgrading measurement and calibration equipment. Lastly, as is often the case in developing countries, technical regulations, even if in place, are often not implemented. Feeble enforcement of technical regulations leads to low demand from the private sector and poor services provided by existing laboratories and research labs. Support would be desirable to set up capacities necessary for implementation. Ultimately, however, effective implementation depends on various other issues, such as the level of corruption and the availability of inspectors, that must be addressed by national policy makers.

Below, we summarise the main opportunities and challenges in each of the examined sectors.

Renewable energy

For this sector, several QI-related recommendations may be considered as the solar PV market further develops, local manufacturing scales up, and opportunities for exporting services and products increase:

- The various investments and developments in solar energy in Morocco in the past decade led to important progress in setting up the necessary NQI. However, several gaps still exist as the market grows, as research activities in this area are expanded, and as export opportunities emerge.
- In particular, we identified the need to support capabilities for adopting relevant standards and improving dissemination channels.

- As the market grows, it is necessary to identify specific equipment needs for testing and calibration for PV modules and balance of system components, especially related to adapting existing technologies to the environmental conditions of Morocco.
- An important gap we identified relates to system installers. We thus recommend supporting capabilities for training and certification of system installers.
- Despite its political nature, it may also be important to support speeding up the accreditation of new testing facilities for solar PV. But, as accreditation procedures are highly political, room for action by development cooperation actors remains limited.

Energy efficiency in buildings

- The energy efficiency in buildings sector has been quite dynamic in the past couple of years. Yet, there is a need for additional standards to be developed and adapted for related equipment (such as lights and white appliances) and for thermal insulation, to supplement the ones that already exist (e.g., ISO standards for public lighting have already been adopted). Because of the regulatory changes of the past year, the private sector is placing increasing pressure on IMANOR to adopt international standards for energy efficiency.
- In addition, there is a need for more testing laboratories. The national laboratory, LPEE, already has some testing and inspection capabilities and other labs exist too, such as CETEMCO, but these are considered insufficient (both in terms of range and volume of services they offer and in terms of quality of service). More investment in building capabilities is needed for laboratories focussed on characterising construction materials (in terms of conductivity, resistance, thermo-physical characteristics, etc.). If indeed a market for local materials for insulation will develop as a result of recent and planned technical regulations, such QI services for conformity assessment could be particularly relevant for Morocco.

Waste management

- Given the current initiatives and programmes in the area of solid waste management and the large potential in this sector, several QI-related interventions could be considered, especially related to waste processing.

- Further adoption and adaptation of standards, especially related to separation and valorisation of waste, is needed. IMANOR's website shows about 20 standards that have been adopted in this area, but it is not clear which types of waste they apply to. In the area of recycling of building materials, standards appear to be lacking entirely.
- Funding is necessary to establish testing laboratories for solid waste and especially hazardous waste. There is an apparent lack of accredited institutions (such as laboratories) working in this area. In particular, testing and characterisation of materials (e.g., to enable sorting of hazardous materials or building materials as purely as possible); testing for recycled products; and testing for air, water and soil quality (e.g., leakage of pollutants) are necessary to support recovery activities.
- Moreover, certification schemes are needed for the recycling processes for paper, glass, aluminium, and building materials, among others.
- Technical regulation (enforcement and market surveillance) is essential to enable action in this green economy sector.

Sustainable transportation

- The sustainable transportation sector is still in the early development stage in Morocco. However, it is expected that its importance will increase in the coming years.
- Given the early stage of development and deployment of related technologies, a needs assessment should be conducted to identify the gaps and opportunities at different system levels more precisely.
- Especially if local manufacturing of electric batteries is envisioned in the short term, adoption of standards and testing and calibration facilities would be necessary, as well as certification schemes.
- As IRESEN is already working on piloting charging infrastructure for electric cars and integration with rooftop PV systems, testing and calibration of charging infrastructure is needed, as well as the adoption of interface standards to ensure inter-operability (between vehicle and network infrastructure). The adoption of standards related to ensuring functional safety and electrical safety for (cross-cutting) system components for EVs is also needed. The German Standardization Road map for electric mobility by 2020 provides a good example for how to

plan the adoption of standards at different phases of market development and along the value chain of EV technology (Nationale Plattform Elektromobilität, n.d.).

- To ensure market development for sustainable transportation solutions, technical regulations regarding urban air pollution and quality of fuels are necessary.

Water management

- The water management sector is well developed in Morocco as, due to scarcity issues, the water sector is a national priority. The QI capabilities are also relatively well developed. But, when it comes to wastewater treatment and reuse, several improvements could be made.
- While national standards related to this sector exist, further adoption of standards related to wastewater treatment and reuse are considered necessary.
- The testing facilities for water quality that are needed for wastewater treatment and grey water reuse are also considered insufficient. Our interviews suggest that while testing labs for such services do exist, they are limited and unable to meet current and future demand.

5.3 Ethiopia

Ethiopia is one the largest countries in Africa, both by territorial size and population; its population reached 109 million in 2018 (World Bank, n.d.). Even after a sustained period of high economic growth, the country remains one of the poorest, ranking 173rd out of 189 (Human Development Report Office, 2019). Climate change adaptation is an important challenge. In past decades, Ethiopia has been exposed to climate change hazards and natural disasters (Medhin & Mekonnen, 2019, p. 289). This will become more serious with further global warming. The country mainly depends on rain-fed agriculture for the survival of its people and its economy. Despite a continuous urbanisation process, Ethiopia's population is predominantly rural (80 per cent as of 2017), a very high percentage even in comparison with other countries of the region.

Ethiopia's contributions to global GHG emissions are insignificant. In 2017, the percentage was estimated by the World Resources Institute to be 0.27 per cent. Of all its emissions, 87 per cent originate from agriculture and forestry, only 3 per cent each originate from transport, industry, buildings and power generation. This might change if the continuous efforts to industrialise are successful and fast urbanisation continues.

Three policy documents frame Ethiopia's stance towards climate change. They postulate the ambitious goals of achieving middle-income country status by 2025, while becoming a carbon-neutral society in the long term:

- The Climate-Resilient Green Economy (CRGE) strategy launched in 2011 frames policies and bundles initiatives, which should help the country achieve its development goals while limiting GHG emissions by 2030. Four pillars are defined: (1) improving agricultural production practices; (2) protecting and re-establishing forests; (3) expanding electricity generation from renewable sources; and (4) leapfrogging to modern and energy-efficient technologies in transport, industry and buildings.
- The Growth and Transformation Plan (GTP) II is the national development plan of Ethiopia for the years 2015 to 2020. Environment and Climate Resilient Green Economy are one of six cross-cutting themes in the Plan (FDRE, 2016).
- The intended nationally determined contribution (INDC) that Ethiopia submitted to the UNFCCC builds directly on GTP II and CRGE. Ethiopia intends to reduce GHG emissions by 64 per cent compared with the business-as-usual scenario by 2030 (UNFCCC, n.d.). Sectors included are agriculture, forestry, transport, electric power, industry and buildings (including waste and green cities).

Considering the urgent socioeconomic needs of one of the twenty poorest countries in the world, it is remarkable that Ethiopia is clearly committed to climate-change-adapted development, focussing first on adaptation and second, on mitigation. However, to keep acceptance and ownership levels at an adequate level, win-win options in the sense of an inclusive green growth will have to be identified and realised.

5.3.1 The NQI system

The current Ethiopian NQI system consists of four QI institutes for metrology, standardisation, conformity assessment and accreditation and regulatory functions mainly in the Ministry of Trade and Industry (MoTI). This setting is the outcome of a 2011 sector reform. Prior to that year, the Quality and Standards Authority of Ethiopia (QSAE) was the single entity covering Ethiopia's NQI. Separating the function into four NQI institutions and overcoming the deficits, while strengthening the regulatory functions of MoTI, was done in alignment with commonly recognised international good practice. Today institutions and functions in the NQI are coordinated by MoTI. The four NQI institutions are

- The National Metrology Institute of Ethiopia (NMIE), which provides calibration services for conformity assessment bodies to ensure measuring equipment meets standards;
- The Ethiopian Standards Agency (ESA), which is in charge of development, adoption and dissemination of national and international standards;
- The Ethiopian Conformity Assessment Enterprise (ECAE), which provides testing, certification and inspection for products and services; and
- The Ethiopian National Accreditation Office (ENAO), which is responsible for issuing accreditation of technical competency of laboratories and other conformity assessment bodies.

The sector reform and the four NQI institutions have received significant long-term support first by one component of the Engineering Capacity Building Program (ECBP) and later by a specific NQI programme. These efforts were implemented by GIZ and PTB, financed by the German Federal Ministry for Economic Cooperation and Development (BMZ) and, as of 2009, co-financed by the European Union. Since 2017, the Ethiopian NQI system has received considerable support through an International Development Association (IDA) credit of USD 50 million, to be implemented between 2017 and 2022. The World Bank programme focusses on three industries: leather and leather products, textiles and garments, and agro-processed products. It aims to strengthen the capacities of the NQI institutions and to foster private sector involvement for the development of the NQI system and the demand for QI services. From 2016 to 2019, PTB supported specific QI services to foster innovation in the agriculture and food sector.

Telfser and Morales (2019) provide a recent assessment of the development of NQI in six areas related to climate change: renewable energies, energy efficiency, meteorology, agriculture, water and human health. Main areas for improvement are seen in the fields of metrology and conformity assessment, for example, for renewable energies, energy efficiency and water. Accreditation and international recognition of services is an important challenge with regard to calibration services provided by NMIE (length, force, volume etc.).

In a project appraisal document, the World Bank and the related Project Information Document/Integrated Safeguards Data Sheet recognise the efforts of the Government of Ethiopia (GoE) and German/EU cooperation, but still see that the four institutions and the system as a whole are afflicted by many challenges: “the NQI institutions lack capacity in human resources, the facility to ensure accurate measurement, well-equipped laboratories to meet industries’ demands, as well as coordination and collaboration with regulatory bodies” (World Bank, 2016a, p. 4).

That World Bank document and papers by Telfser and Morales (2019) both mention a number of supply-side shortages in the Ethiopian NQI system, such as a lack of accredited calibration services in some scopes or testing capacities for water quality. However, some of the problems seem to lie deeper and be related to demand-side issues and elements of system failure. One indication is that in standardisation and technical regulation, implementation lags behind standards development.

In the field of metrology, Telfser and Morales (2019) mention a series of services provided by NMIE that are relevant in the context of climate change and renewable energies development, for example, energy meters and insulation testers. Other were still missing at the time of their assessment, for example, water flow measurement or calibration services for pyranometers (a device for measuring solar irradiance).

With regard to conformity assessment, the World Bank diagnoses what is akin to a “chicken and egg problem”. On the one hand, challenges relate to the supply side: “ECAE lacks adequate modern testing instruments to provide demanded services for the targeted sectors” (World Bank, 2017, p. 73). On the other hand, the demand-side is also underdeveloped: “there seems to be little incentive for the private sector to invest in this space unless sufficient demand is created from industries and consumers" (World Bank, 2017, p. 73).

With regard to accreditation, the main challenge mentioned by World Bank is that ENAO is still not fully recognised internationally. ENAO has been a full member of ILAC in the fields of testing, medical testing and inspection since November 2017. The IAF multilateral recognition arrangement has not yet been signed. Lack of international recognition is one factor that has also hampered the outreach of ENAO and led to a relatively low number of accredited testing, calibration and medical laboratories. In addition, a number of conformity assessment bodies have decided not to opt for a re-accreditation by ENAO, because they assessed the costs as not being rewarded by the market. This might begin to change with full international recognition of ENAO.

One of the structural problems hindering the development of Ethiopia's NQI system is that a broad-based structural transformation and modernisation of the national economy and society has not happened at the speed that was projected in the main policy documents. By this we mean the transition from a traditional rural society based on agriculture to an industrialised society that is an export-oriented, light-manufacturing hub in Africa. A fast and broad-based industrialisation would scale up the demand for conformity assessment and calibration services for an increasingly broad array of products. Private providers of conformity assessment services would emerge, offering services that ECAE does not provide. Conformity assessment services must be based on up-to-date measurement capacities and accredited by an internationally recognised entity to be relevant for companies wishing to enter global value chains. Thus, under conditions of a structural transformation, positive feedback loops between metrology, standardisation, conformity assessment and accreditation would strengthen the NQI infrastructure. However, this transformation has not yet happened. Manufacturing as a percentage of exports has remained slightly below 13 per cent in past years, and modern agribusiness exports (e.g., cut flowers) have been stagnant since 2015 after years of dynamic growth.

In a poor society with an incipient middle class, impetus for a quality-oriented business strategy must come from international markets, either directly through the quality demanded by the international goods markets, or, indirectly through specifications of lead firms in global value chains.

Without this kind of international exposure and/or related mandatory regulations, even quality-oriented companies would not seek out relatively expensive certificates of conformity assessment. In 2015, only 13 per cent of all manufacturing firms in Ethiopia had a quality management certificate (ISO 9000; ISO 14000), a figure that had remained nearly unchanged since 2011 (World Bank, 2017, p. 72). Most companies with management standards were found in the textile/garment and leather sectors, which are both very outward-oriented industries (World Bank, 2017, p. 72).

Most of the mentioned challenges have already been addressed by ECBP and NQI programmes. The World Bank plans to achieve significant and sustainable impact by channelling considerable financial resources to QI services that address the mentioned sectors, which were identified by the GoE as having specific strategic importance. Indirect effects on the country's green economy strategy can be expected, as two of the three focus sectors are important as sources of GHG emissions (agriculture) or process-related risks of environmental contamination (leather).

5.3.2 Renewable energy systems

Energy is a core sector for the green transformation of most countries in developing countries, including Ethiopia. In the following, we give an overview of the challenges in Ethiopia's energy sector and then discuss decentralised solutions for energy access, seen as temporary and bridge solutions in the Ethiopian context. We then discuss in more detail the development of two core utility-scale renewable energy technologies (wind and solar PV).

Energy: sector structure and sustainability challenges

In the fiscal year 2016/2017, Ethiopia had a total power generation capacity of around 4.3 gigawatts (GW). This capacity has been growing in recent years, but the ambitious plans in GTP II of enlarging generation capacity to more than 17 GW in 2019/2020 will not be reached. Energy demand is growing by around 10 per cent annually due to population growth and a growing access in urban and rural areas. Ethiopia is currently exporting electricity to neighbouring countries. Increased exports are expected once the Grand Ethiopian Renaissance Dam (GERD) begins operating.

Fossil fuel combustion has played a minor role in Ethiopia's energy matrix. Only 8.6 per cent of all energy used comes from oil and less than 1 per cent from coal. Almost 88 per cent of the energy consumed is based on biomass and waste and 2.6 per cent from (mainly large) hydropower. Although these sources are classified as "renewables", they do have impacts on the environment and human health (see below). Only 0.2 per cent of all energy comes from modern versions of renewable energies, to date nearly exclusively wind. Solar and geothermal are in the pipeline.

One key challenge is to rapidly increase the percentage of people with access to high-quality energy. The expectations of the population in this regard are high and failure to meet them may endanger political and social stability. Recent World Bank data shows that 56 per cent of the population has no access to reliable electricity, 11 per cent have access through mini-grids and 33 per cent have access via grid connection (FDRE, 2019). Non-availability of electricity for households is an element of poverty and a factor of environmental degradation. Traditional burning of firewood, which is most often not obtained sustainably, is an important factor leading to deforestation and other forms of ecosystem debilitation. Incomplete burning of biomasses contributes to indoor and outdoor air pollution and constitutes a threat to human health. In addition, black carbon, as a by-product of traditional combustion of biomasses is a potent accelerator of climate change. Thus, bringing electricity (based on renewables) to traditional (often rural) households will combine beneficial health and environmental effects.

Currently, the country faces severe challenges related both to expanding electric generation capacity and to the number of grid-connected households. The gap between the achieved generation capacity and the ambitious targets is due to severe delays in the implementation of some large electricity generation projects, such as GERD. Currently, the completion of GERD is projected for 2022. Non-traditional renewable energy projects are still rather incipient, but the country bets on wind, solar and geothermal energy. The GTP II stipulated the goal of building up significant quantities of new renewable capacity from sources other than hydroelectric in order to diversify the Ethiopian energy generation mix.

The main increase in power generating capacity in GTP II was assigned to hydropower, which was supposed to contribute 80 per cent of electric power generation by 2019/2020. Of this, 1.2 GW would come from wind, 0.3 GW from solar power and the remaining capacity from a series of other sources (waste, sugar, other biomasses). The planned figures of GTP II will not be reached on time. Geothermal energy might become an important source of clean energy in the long run, as the East African Rift Valley has a huge generation potential. Improved cookstoves (ICS) and off-grid/mini-grid solutions are seen as bridging solutions until universal grid-connections can be ensured.

Decentralised and transitional solutions for energy access

ICS have advantages over traditional cooking. They use less biomass and may, thus, contribute to reducing deforestation and other forms of degradation of ecosystems. Indoor air pollution is reduced and the decreased need to collect firewood allows household members (mainly women) to contribute to income generating activities or, for example, pursue education.

ICS diffusion in Ethiopia dates back to the 1970s (SNV/ERG/MGP, 2018). From the late 1980s onwards, World Bank and later the German Technical Cooperation Agency (now GIZ), promoted ICS development and diffusion. Charities and NGOs are additional promoters of ICSs. The CRGE strategy commits to promoting ICSs that will be used by about 20 million households and reduce GHG emissions by almost 35 metric tons of carbon dioxide equivalent ($MtCO_2e$) by 2030 (FDRE, 2011). Still, in 2018, only 7.2 per cent of the Ethiopian population had access to clean cooking facilities, far below the regional average of 17.2 per cent in Sub-Saharan Africa (IEA, 2020; n.d.).

Stove performance testing has been done repeatedly by public institutions, development agencies and NGOs. Most of these efforts show that fuelwood consumption and indoor air pollution are significantly reduced by their usage, compared with traditional three-stone, open fires. Concrete data, however, varies significantly. Large discrepancies have been found between laboratory testing and field tests. Gebreegziabher et al. (2018, p. 173) come to the conclusion that "solid data on the performance of improved biomass cooking stoves remains scarce". Recent tests of one of the widely diffused ICSs concluded that most of them have a very low performance on all relevant criteria, such as indoor and outdoor emissions of CO_2 and particulate matter, thermal efficiency and fuel wood consumption, indicating "that concerted effort should be exerted to alleviate the poor efficiency of the stoves [that] are used by [the] majority of the people in Ethiopia" (SNV/ERG/MGP, 2018, p. 48).

Recent studies make clear that there is scope for action in quality assurance for ICS. In 2017, an ESA biomass stove standard was adopted (ES 6085:2017). In 2019, ISO approved a standards family related to laboratory and field-testing methods for "Clean cookstoves and clean cooking solutions" (ISO 19869:2019). ESA is participating in the relevant ISO Technical Committee 285.

Under the Alternative Energy Technology Development and Promotion Directorate (AETDPD) of the Ministry of Water, Irrigation and Energy (MoWIE) a team of experts has been working in the ICS field and had at its disposal a "workshop and laboratory equipped with machines, tools, equipment, and facilities required for the designing, prototype production and thermal efficiency testing of cookstoves and related technologies" (SNV/ERG/MPG, 2018, p. 48). The same report describes recent institutional reforms: "the institutional frame has been split into two recently and the national improved cookstoves program (NICS) is housed under the MoEFCC while some technical capability is left at the AETDPD under the MoWIE" (SNV/ERG/MPG, 2018, p. 75).

Three arguments indicate that it may be a good time to start ICS-related NQI interventions:

- It is fairly certain that large-scale distribution of ICS will remain high on the Ethiopian agenda in the foreseeable future. In addition, ICS have a limited life span and have to be replaced after a couple of years. Thus, there is scope for introducing stoves of higher quality to the markets.
- With the recent ISO standards for ICS testing there are now internationally recognised procedures for assessing fuel saving and emission reduction performance that should be streamlined in Ethiopia.
- Recent institutional reforms in the field can imply an opportunity, for example, to establish an effective and accredited test laboratory for ICSs, based on ISO standards.

Box 3: Off-grid options for electricity access

In its aim of approaching universal energy access, the GoE bets on a combination of grid and off-grid access. The Development Bank of Ethiopia (DBE) supports the deployment of solar lanterns, solar home systems, solar water pumps and mini-grids (solar, wind, biomass). Between 2012 and 2018, more than 1.1 million solar lanterns and 72,000 SHS have been rolled out. Mini-grids are seen as an alternative to stand-alone solutions, such as SHS. They can offer high-quality energy on a stable basis and allow small-scale business applications. In GTP II, mini-grids are mentioned as a solution to supply currently unconnected communities with quality electric power until grid connection can be achieved.

The GoE's ambitions to bring off-grid solar-energy solutions to Ethiopia is receiving substantial international support and funding, particularly from the multi-donor World Bank-based agency Lighting Global (LG). LG has developed its own quality assurance framework for solar lanterns and SHS consisting of standardised product definitions and classification systems, test methods and performance metrics. Core elements of the LG standards refer to

- truth in advertising, that is, marketing material must reflect the tested product performance;
- lumen maintenance and durability;
- system quality and safety; and
- warranty.

Market Check Method (MCM) testing consists of random sampling and retesting of products on the market to verify that products keep their performance level over time. Conformity assessment of LG standards is done by a network of accredited laboratories, one based at the University of Nairobi. On its website, LG publishes all products that have passed its quality assurance and, thus, encourages acquisition. To streamline importation of off-grid solar products, in September 2018, the Council of Ministers approved certification of products before shipment (i.e., pre-export verification of conformity to standards) (Lighting Global, 29 May 2019).

For the most important off-grid solar products, the LG quality assurance system covers the relevant NQI dimensions. One opportunity that actors involved in NQI related development cooperation might wish to explore is related to conformity assessment. For a couple of years ECAE has been in possession of a testing facility for solar PV at its electric testing lab that seems to have been under-utilised. After approval of PVoC by the GoE it is unlikely that the equipment will be used for domestic purposes on a large scale. PTB might consider connecting with LG to see whether ECAE could become a further accredited testing lab in the LG network. At the same time, it might be useful to enhance ECAE's capacities in dealing with the new PVoC regulations.

Utility-scale renewable energy projects

The International Energy Agency's African Energy Outlook estimates that only 1 per cent of the 10 GW of wind energy potential in Ethiopia is in fact used (IEA 2014, Chen 2018). During the GTP I period (2010-2015), three wind farms were inaugurated in the country:

- Adama Wind Farm I, commenced in 2011 and inaugurated in 2012 (51 MW);
- Ashegoda Wind Farm, commenced in 2009 and inaugurated in 2013 (120 MW); and
- Adama Wind Farm II, commenced in 2012 and inaugurated in 2015 (153 MW).

Additional sites for wind farms have been identified, with capacities ranging between 42 MW and 300 MW. To date, all wind farms have been implemented as turnkey projects with international project developers signing a contract with Ethiopian Electric Power (EEP). Project developers were the France-based Vergnet Groupe (in Ashegoda) and HydroChina (in Adama). All turbines were imported, partly due to a lack of local manufacturing capacities, partly as the result of a contractual agreement in the case of HydroChina.

Chen (2018) identifies some QI-related problems in the project implementation that confirm findings from interviews during the field study. The contract for the Ashegoda wind farm had clearly stipulated that imported turbines would have to come with a certificate from an independent party, based on IEC 61400. However, EEP project managers only found out during the construction process that Vergnet had not ensured the requested certification. After negotiations, the project developer changed part of the turbines, leading to the situation that the wind park operates with two different types of turbines (Chen, 2018). This makes maintenance and repair work more difficult. One of the interviewees from EEP stated that around 30-40 per cent of the wind turbines of the Adama wind park are currently not working or fail frequently. He explained that, like in Ashegoda, the turbines in Adama had arrived without third party certification.

The Metehara solar PV plant in Oromia region will be the first utility-scale solar energy project in the country, with a capacity of 100 MW. Metehara Project was supported by the World Bank-based Scaling Solar Program.

Scaling Solar brings together a series of World Bank Group services under a "one-stop shop" approach. It aims at making privately-funded, grid-connected solar projects operational within two years and at competitive tariffs. Under Scaling Solar, EEP has published a series of tenders for utility-scale solar projects that might reach a total of 500 or even 750 MW in the next years. In July 2019, six solar power projects with an aggregate generation capacity of 800 MW were reported to be in the bidding process. As is the case with Metehara, all projects follow the International Power Producers model to be developed by foreign engineering, procurement and construction (EPC) companies. The bidding companies originate from Europe, the Middle East and North Africa, India, South Korea and Japan. Only in one consortium is a local (Ethiopian) company included.

In general, an increasing number of utility-scale wind parks and solar PV projects can be expected to be established in Ethiopia in the coming years, supported by donors and international organisations. It can be assumed that in the near future international EPC companies and project developers will implement all or most of the projects. This is not only the case in Ethiopia. A large-N study by Steffen et al. (2018) indicates that even in more advanced economies, international EPC companies play the dominant role in the implementation of clean energy projects of a certain scale, at least in the early stages. Considering the limited capacities of Ethiopia for complex engineering work, it is unlikely that local project developers will enter the process in the next years. Thus, if Ethiopia pursues its goal of rapidly enlarging non-hydro renewable energy generation, it would be well advised to develop mutually beneficial working relationships with international project developers.

5.3.3 Sustainable transportation – focus on rail-bound passenger and freight transport

The CRGE strategy sees the highest potential for reducing GHG emissions in the substitution of road by rail transport.[95] Thus, we will focus here on the rather advanced transition towards electric transport. Two large projects

95 In 2019, the ratio of cars to people in Ethiopia was 2 cars to 1,000 people - one of the lowest rates of car ownership in the world. There are only 600,000 registered cars in Ethiopia and 84 per cent are taxis (BBC, 14 November 2019).

have been implemented in recent years, the Addis Ababa-Djibouti Railway (AADR) and the Addis Ababa Light Rail Transit (AALRT) system.

The construction of the AADR started in 2011, and trains transporting goods and passengers started operating in January 2018. The railway links Ethiopia's capital with the Port of Doraleh in Djibouti. The total cost of the project was USD 4.5 billion. The China's Export-Import Bank (Exim Bank), China Development Bank, and Industrial and Commercial Bank of China partially funded the project through concessional loans of nearly USD 3.3 billion (Dreher et al., 2017).

The China Railway Group Limited (CREC) and the China Civil Engineering Construction Corporation (CCECC) were in charge of the project after being awarded an EPC contract with the Ethiopian Railways Corporation (ERC). Due to a shortage of skilled railway personnel, the CREC and CCECC were contracted to manage the operations of the AADR until 2023.

In parallel to the Addis Ababa-Djibouti line, Chinese actors implemented a second railway project: The AALRT network, currently a two-line, 34.4-kilometer system connecting city districts in North-South and East West directions, approximately. Construction on the AALRT started in December 2011 after securing funds from China's Exim Bank. The railway started to operate in late 2015. The final cost of the railway was USD 475 million, 85 per cent of which was covered by a concessional loan from Exim Bank. It took three years for CREC to finish the main work. Even if ERC is the owner of the system, it is managed by a Chinese company, Shenzhen Metro Group. Official data state that the system carried on average 105,000-110,000 passengers daily in the first 14 months of operation.

The Addis-Djibouti line is not the end of the electrification of inter-urban transport. Currently, the 447km Awash – Woldia – Hara Gebeya railway project is under implementation, partly developed by the Turkish infrastructure firm Yapı Merkezi. How fast further projects may be implemented mainly depends on the debt capacity of the country and/or the willingness of the international donor community to offer access to finance.

Implementation of both railroad projects is assessed as relatively successful by interviewees and experts. Some stated that the Chinese partners were highly motivated to guarantee success, as AADR is seen as part of the Chinese Belt and Road Initiative and both projects are showcases to support China entering the African railway market. There were a series of QI related issues in both projects. During the construction phases, equipment was procured and used which could only partly be calibrated by NMIE. Calibration in some fields was, thus, done by the contractors. Ethiopia is in the process of drafting its own railroad standards and ESA is participating in ISO Technical Committee 269. In addition, parts of the rolling stock have been failing repeatedly.

The most relevant entry point for NQI-related support to the Ethiopian railroad system is the planned Ethiopian Railway Academy (ERA), under the ERC. Once completed (currently scheduled for 2020/21), it will host up to 1,000 trainees. ERA is working with Technical and Vocational Education Training colleges and universities, for example, the Addis Ababa Institute of Technology (AAIT). The vision is that ERA will provide services not only to Ethiopia but also to additional countries in the East African region. ERA is mainly financed by grants from China and World Bank. Working relations between ERC and the NQI exist in several ways. For instance, ERC uses calibration by NMIE for electrical equipment and pressure gauges. This kind of QI services might be streamlined and scaled-up under the ERA.

5.3.4 Solid waste management

Solid waste management is a sustainability challenge of growing importance in Sub-Saharan Africa. Volumes of waste are increasing, and its composition is changing, from mainly traditional organic matters to other elements, such as plastic and electronic waste.

In our study, we focus on the most significant approach to dealing with the municipal solid waste challenge in Ethiopia's capital: combustion to generate electricity. This has been in the focus of policies and public debates during the past years; alternative options, such as avoiding waste or increasing recycling rates have not been tested.

Addis Ababa's municipal solid waste has been deposited on an open dumping site in Koshe for several decades. The landfill covers around 37 hectares of land today, with the waste layer reaching 40 meters in height. In order to remedy this situation, the political decision was to go for a large-scale waste-to-energy project. The project, called "Reppie", emerged as a partnership of EEP with three international companies. The project took four years to complete at a cost of close to USD 3 billion. It was fully financed by the GoE.

Reppie was expected to process 1,400 tonnes of municipal solid waste per day and generate 50 MW of electricity, potentially serving 30 per cent of Addis Ababa's households with electricity. Inauguration of the Reppie plant by the former president of the country took place in 2018, after a delay of at least 12 months compared with planning. Soon after its start, it became clear that the promised capacity in electricity generation would not be reached and only 25 MW would actually be delivered. Operation was discontinued for several months. A paper published in 2018, and written before the Reppie inauguration, lists some of the main challenges of the project from which possible entry points for NQI interventions can be derived (Abebe, 2018). Many of the challenges arise from a deficient management and monitoring of the waste-to-energy value chain. The energy harvest from waste depends on the composition of the waste to be incinerated. Even if the composition is gradually changing, most municipal solid waste in Addis Ababa is still humid and organic and, thus, tends to have a low calorific value. Not only does this reduce the amount of energy that can be generated per tonne of waste, but it also generates technical challenges that mainly affect the incinerator, which is at the core of and is the costliest element of the facility.

Deficient waste separation and process monitoring can also lead to environmental problems. Substandard incineration processes and deficient flue gas purification may lead to emissions of PM, volatile organic compounds, heavy metals, dioxins, sulphur dioxide, carbon monoxide, mercury and furans. In addition, handling of the toxic residues of the incineration process (bottom ash) has to be done carefully.

Whether or not the Reppie project can be "rescued" cannot yet be answered. Interviewees assessed Reppie as "too big to fail". Possible actions to significantly improve the situation go beyond the scope of narrow NQI interventions. Observers see the main challenge is establishing a clear and transparent waste handling to ensure that only substances with a high calorific value enter the combustion process, while wet organic matter and dangerous substances are treated separately.

The Reppie plant will continue functioning for at least a couple more years as recycling capacities are very scarce. The facility might even serve to incinerate parts of the accumulated masses of garbage that have been deposited at Koshe dumping site for more than half a century. What seems to be of high importance is to assess the quality of environmental monitoring around the Koshe/Reppie site. The project developers stated that monitoring of air, water and possible soil contamination is based on European standards. Whether this is really the case could not be assessed during the field study and literature review.

5.3.5 Sustainable agriculture and land management

Agriculture is the backbone of Ethiopia's economy and the livelihood of the majority of the population. A country profile by CIAT/BFS/USAID (2017) provides the following agricultural statistics for Ethiopia. Agricultural land occupies around 35 per cent of total land area. Land fragmentation has led to a structure in which very small plots of 0.5-2 ha dominate among the approximately 17.5 million agricultural land holders. Only 1.2 per cent of the total agricultural land area is controlled by farms larger than 10 ha. The main crops in Ethiopian agriculture are teff, maize, sorghum, wheat, barley, coffee, beans, chickpeas and potatoes. Since the beginning of the century, cut flowers have emerged as an important commercial crop, employing 40,000 women and men on 1,500 ha of land in fiscal year 2016/2017. In addition, cattle raising for milk and meat is widespread. Ethiopia hosts one of the largest cattle herds worldwide. Agriculture in Ethiopia is almost exclusively rain-fed and only 2-3 per cent of the cropland is currently irrigated (CIAT/BFS/USAID, 2017). Greening Ethiopia's agriculture has to be conceptualised as an environmentally and socially sustainable intensification of the production of both staple and commercial crops, while lowering the GHG-intensity of growth.

The CRGE prioritised a suite of initiatives to limit emissions stemming from land use change and deforestation (FDRE, 2011, p. 23):

- Intensify agriculture through usage of improved inputs and better residue management to decrease demand for additional agricultural land and reduce deforestation;
- Create new agricultural land in degraded areas through small-, medium-, and large-scale irrigation; and
- Introduce lower-emission agricultural techniques, ranging from the use of carbon- and nitrogen-efficient crop varieties to the promotion of organic fertilisers.

Part of Ethiopia's industrialisation strategy as laid down in GTP II bets on the establishment of industrial parks, among them integrated agro-industrial parks (IAIPs), as a key strategy for transforming the economy by linking agriculture with the industry to enhance value addition through agro-processing. Commodities intended for processing include coffee, sorghum, maize, sesame, horticulture, meat and dairy, and cereals. The IAIPs will include companies that export value-added agricultural products as well as those producing products for domestic consumption.

The Agricultural Growth Program (AGP) is the government programme to support the objectives of GTP II (FDRE, 2015). It is a multifaceted investment programme supporting agricultural productivity and commercialisation focussing on high agricultural potential areas to address some of the key constraints to agricultural growth and thereby contribute to overall economic growth and transformation. AGP aims primarily at increasing productivity of both agriculture and livestock and improving nutrition on the household level (EIAR, n.d.).

The AGP II document mentions a series of required activities with direct relation to NQI (FDRE, 2015):

- strengthening diagnostic capacities of the National Animal Insemination Centre (NAIC) to ensure appropriate testing of the quality of semen (p. 3),
- strengthening the central quality control laboratory of the Veterinary Drug and Feed Administration and Control Authority (VDFACA) (p. 33),
- supporting the national seed quality analysis laboratory (p. 39), and
- strengthening Central and Regional Soil Testing Laboratories (p. 41).

5.3.6 Overall implications for NQI interventions

At the system level, implementation capacities for large engineering projects are underdeveloped in Ethiopia, as exemplified by the Reppie waste-to-energy plant and several recent projects out of the scope of the present study, such as GERD and a series of sugar factories. Project failures, cost overruns and delays in project implementation not only challenge the green transformation, but have contributed to a severe debt burden of the Ethiopian state, which increasingly narrows the room for manoeuvre. More than ever, any large-scale project, whether financed by donors or the GoE and its credit lines, has to pass the test of cost-benefit ratio and failure protection. This is relevant for “green” projects as well as for others.

During the next decade, which is the scope of the present study, it is rather unlikely that the country will start to develop new large-scale green projects in the analysed sectors. A crucial cross-cutting challenge is therefore to capacitate national entities to become competent partners of the abundant international actors who are willing to contribute to the ambitious development plans of the country, including the CRGE and NDCs. These enter cooperation with (in the case of foreign direct investment and project developers) or without (development cooperation, charities) own interests.

NQI-related development cooperation should check the usefulness of and opportunities to significantly increase the number of decision makers and personnel in relevant state entities (EEP, ERC, MoWIE, etc.) duly capacitated in project (ISO 21500), quality (ISO 10005) and risk (ISO 31000) management. This might be an important step to establish local authorities as eye-level partners with international actors and, also, to choose the most appropriate development partners. Capacity building requirements are highly relevant for QI aspects and are often underrated factors of project design and implementation.

The green transformation affects many different sectors. Although it is not always the case, the most effective way forward should be seen in offering all required NQI services locally. This might tie up time and money, compared with bringing in service providers for certain tasks that do not require a permanent presence. A first important step consists in preparing state institutions in charge of implementing large-scale projects to use quality thinking and QI concepts intelligently. The Reppie waste-to-energy facility ran into severe problems because basic quality aspects (classification of waste types) were not considered in the project design. The existing wind parks might work much more smoothly today had EEP project officers ensured that turbines entering the country held quality certificates from accredited third parties.

Strengthening NQI for the green transformation cannot be conceptualised as necessarily involving test capacities based on state-of-the art measurement capabilities. The costs for equipment, specialised trainings and reference materials have to be balanced with the number of items to be tested. One positive example is, without doubt, the dissemination of ICSs, which is seeing millions of units being diffused and local manufacturing being involved. We identified a window of opportunity in this context. In the case of wind energy, building up local capacities for testing of materials (blades and towers), mechanical and electronic components and system integration would imply shooting at sparrows with cannons and adding expensive white elephants to the system. With the number of units coming to Ethiopia only in dozens per year, and not hundreds or thousands, this seems out of scale.

There is some evidence that the Ethiopian NQI system is not suffering from supply-side constraints. In our understanding, the design of Ethiopia's NQI is aligned with ambitious plans for economic diversification and industrialisation. Available data indicate that this quantum leap in the overall economy is yet to materialise. Both conformity assessment and accreditation are suffering from a lack of tangible demand from the business sector today. At the same time, response times of NQI institutions to testing demands have been characterised as inflated, which has not helped the reputation of the system. PVoC for solar products is a response of the GoE to these challenges and related complaints.

We assume that a series of green projects will be implemented in the next decades, for example, in wind, solar PV and geothermal energy. Executing actors will be international project developers. A healthy relationship between local entities and international project developers is, thus, crucial. Development cooperation might consider approaching project developers to offer cooperation in the field of quality assurance. As this would imply win-win opportunities, it might be relevant for PTB and other development cooperation actors to promote public-private partnership models of cooperation and access the relevant BMZ resources, at least when project developers are located in Europe.

Many QI-related interventions would make sense if embedded in larger programmes and projects. It is thus important that the wide and diverse donor community is informed about and aware of the services that German development agencies, like PTB, offer and the experience they have gained in Ethiopia and other countries. Relevant agencies should participate in donor coordination bodies, such as the Rural Economic Development and Food Security Sector Working Group for the agricultural sector. GIZ has a good standing among NQI-related ministries and agencies. Any green transformation-related interventions can capitalise on this social capital, which has been built up since the beginning of the Engineering Capacity Building Program in 2004.

Below are a few more specific sector-related implications for QI interventions.

Renewable energy

- Strengthening of QI-related services for ICS quality assurance, such as adopting standards, establishing an effective and accredited test laboratory, streamlining procedures for assessing fuel saving and emission reduction performance, is needed. Also, conducting QI need assessments in this area would be relevant.
- For utility-scale renewable energy projects, mainstreaming QI knowledge among decision-makers and staff in entities in charge of hosting large energy projects is critical.
- In addition, for such large-scale projects, QI development cooperation actors may link up with EPC companies to ensure that QI aspects are adequately covered in projects, and spillovers to Ethiopian NQI are facilitated.
- Even if most renewable energy equipment will be imported and selected by the project developers and if PVoC procedures are accepted as sufficient, staff in the contracting agencies should be well trained in quality-related aspects of renewable energy technologies, including basic technical aspects, such as performance ratio, light-induced degradation and light- and elevated-temperature-induced degradation in the case of solar or torque in the case of wind.
- In the coming years, project developers will be core actors in implementing renewable energy projects of a certain scale. German cooperation agencies might consider approaching these companies and positioning themselves, in cooperation with the NQI Institutions of Ethiopia, as partners for the QI elements of their projects. When European companies are selected as project developers, their investments are eligible for the BMZ develoPPP facility.[96]
- Transcending the limits of a traditional NQI project would be an approach to contribute to a conducive knowledge and service environment for

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96 develoPPP.de was set up by BMZ two decades ago to foster the involvement of the private sector in areas where business opportunities and development policy initiatives overlap. BMZ offers financial and technical support for companies that want to do business or have already begun operating in developing and emerging-market countries. The company is responsible for covering at least half of the overall costs.

utility-scale renewable energy projects. Such a conducive knowledge and service environment could consist, for example, of high-quality wind-speed and solar radiation, and geological and pedological maps.

Sustainable transport

- The most relevant entry point for NQI-related support in the transport sector in the years to come will be support to institutions facing the tasks of taking over operation and maintenance of railroad projects from foreign developers, mainly from China, but also from Turkey. The main partner in these efforts would be ERC. Existing links between ERC and NQI institutions (ESA for standards development and NMIE for calibration services related to gauge, pressure and electricity) could be strengthened.
- A railway academy (ERA under ERC), potentially with outreach beyond Ethiopia, is in the pipeline. This institution could be supported to be able to provide training and other services to the Ethiopian railroad system and to strengthen the institutional landscape around green projects.

Solid waste management

- Most interventions needed to improve solid waste management go beyond the scope of QI development cooperation actors. The most significant need would be, to establish a municipal solid waste value chain and separation system. This would be required both for continuing with the waste-to-energy approach and for alternative concepts, such as a circular economy approach.
- Assistance may be necessary to assess and improve the quality of environmental monitoring around the recently inaugurated waste management plant “Reppie” (including types of equipment used, status of calibration, etc.).

Sustainable agriculture and land management

- As indicated by PTB (2019, p. 15), QI services are highly important for greener and climate-resilient agriculture in three sectors: pre-production (resilient seeds, fertilisers and pesticides); production (water, soil nutrients and carbon, as well as pest management); and post-harvest (climate-proof storage facilities). This is also certainly the case for Ethiopia.

- There are also options related to associated areas, such as meteorology and water management. The GoE is implementing comprehensive strategies of a climate-smart agriculture and receives considerable support from large international organisations, research institutes and charities. The size and variety of the donor landscape make it difficult to identify windows of opportunity to include QI aspects in comprehensive support programmes to the agricultural sector. It is important that the services that QI development cooperation actors, such as PTB, can offer are well-known in the Rural Economic Development and Food Security Sector Working Group, which was established in 2008 to provide a platform for donor coordination in the sector.
- Considering the unique selling position and experiences of German development cooperation in general, and PTB specifically, the clearest entry point for QI-related interventions can be seen in strengthening testing labs for soils and seeds and in the field of livestock production. Demand from the Ethiopian side is evident and laid down in strategy documents. Strengthening labs and accompanying them to accreditation could be conceptualised independently from being embedded in larger technical cooperation projects. Linking lab upgrading and accreditation with preparing Ethiopia for climate change might offer opportunities for accessing climate finance and, thus, ensure financial sustainability for the specific QI interventions.

5.4 Comparative perspectives

Comparing the three country case studies allows for some noteworthy conclusions to be drawn, both on the overall NQI systems in countries with different patterns of development, as well as on the nature and depth of the transition to a green economy and the corresponding needs in terms of QI interventions. Below we briefly highlight the main insights.

5.4.1 QI capabilities for the transition to a green economy

The maturity and therefore the effectiveness of the NQI systems differ across the three countries. As a large and growing emerging economy, India's NQI system is well established and internationally recognised, with strong domestic QI capabilities across the entire range of QI services. Gaps do exist in various areas of QI interventions in the green technology sectors (as we discuss in Section 5.4.2), yet, closing these gaps may be feasible given the close integration of the different NQI system components. From this point of view, little support at system level may be necessary; instead, more targeted interventions to close specific technology and knowledge gaps could be considered.

Morocco's NQI system has been improving over time but weak capacity and coordination across components remains problematic. Some of the remaining problems relate to low capabilities in some areas (for instance, many standards have been adopted but they are not visible to relevant stakeholders), low awareness in the private sector, and weak technical and testing capabilities in several green technology sectors. Increasing QI awareness within the private sector and improving the QI system as a whole would have positive repercussions on the green transformation in Morocco. In addition, expanding accreditation and improving international recognition seems necessary.

Ethiopia's NQI system appears to be better established relative to the case of Morocco, for instance, especially due to a major system reform (in 2011) and various long-term development cooperation programmes in this area. Important system level gaps have been identified in metrology and conformity assessment. As in the case of Morocco, expanding accreditation and improving international recognition are important opportunities that need to be addressed.

Despite these differences, we can also identify some commonalities related to QI capabilities, especially in relation to the transition to a green economy in these countries:

- *QI services should be closely aligned with technology level strategies*. When this has been the case (e.g., energy efficiency in buildings in India), diffusion of green technologies has happened more quickly. A failure to do so (e.g., solid waste management in Ethiopia) is likely to significantly slow down the transition to more sustainable practices. This also emphasises the necessity of conducting QI needs assessments for specific sectors. With a few exceptions (energy efficiency in India and metrology needs for solar PV in Morocco), such needs assessment efforts were not conducted, which has implications not only for the speed of transition but also for the coordination across stakeholders and the effectiveness of interventions.

- *System integration (and respective QI capabilities) is highly needed and relevant for several green technologies*. This is the case for technologies such as sustainable transportation (grid stability as a result of e-mobility, renewable energy for charging stations), electricity generation (smart grids to balance and manage different sources of energy), and desalination (increasingly relying on solar and wind), for example. Knowledge on needed QI is still limited in this area and domestic capabilities (also in terms of identifying needs) is especially low.
- *Awareness related to QI and its various benefits for the economy, the environment and society remains limited and should be expanded.* Green economy issues are relatively new for consumers, the private sector, and QI staff. Hence, awareness regarding the green transition along with awareness for quality issues is needed everywhere, as well as training on these new technologies. Low awareness reduces the demand for QI even when the environmental problems are acute (e.g., Morocco, Ethiopia). The more the private sector is sensitised to the relevance of QI, the more it will demand standards and conformity assessment services, for instance. Considering the fact that the transition towards a greener economy has a public goods character, it might be necessary to bring conformity assessment costs down using subsidies, thus, lowering the barriers for private companies.
- *Implementation capabilities need to be strengthened (but to different degrees) in all these cases*. Several factors contribute to low implementation capabilities: lack of technical knowledge on specific technologies (in all cases as we will see below), lack of staff (e.g., India), lack of compliance, weak surveillance, corruption (e.g., Morocco, Ethiopia), and unclear sub-national governance structures (e.g., India). Understanding why implementation capabilities are weak in a particular country and sector is important for designing effective interventions.

5.4.2 QI capabilities for specific green technology sectors

Some similarities and differences across countries can also be observed when we zoom into specific green technology sectors. A general point that emerges from our study is that the transition to a green economy will rely on different technologies depending on a country's resources, needs and capabilities. Some technologies must receive higher priority in specific contexts (such as air pollution monitoring in India, for example), while others are important for all contexts (such as renewables, energy efficiency in buildings and solid waste management). Thus, in light of unique national priorities and capabilities, interventions should be customised.

Renewable energy, a critical sector in all three countries,[97] shows very different patterns not only in terms of the choice of technologies (mostly solar PV and wind in India; CSP, wind, and increasingly solar PV in Morocco; wind, hydro and some solar in Ethiopia) but also in terms of the value added and the technological capabilities that exist locally. India is among the global wind turbine manufacturers and has a certain level of indigenous solar PV manufacturing. This is already reflected in solid NQI capabilities, except, perhaps, know-how on smart grids, which is an emerging technology in India too. In Morocco and Ethiopia, on the other hand, these sectors rely heavily on foreign investment. Yet, in Morocco, domestic capabilities regarding project development, operation and maintenance, including some associated QI services already exist, even if they are still weak; while in Ethiopia, most capabilities are provided by project developers.

Energy efficiency in buildings, as explored in the India and Morocco case studies, also shows large differences between the countries. India followed a well-coordinated approach to develop a market for related technologies (through adopting standards, labels, and certification schemes, as well as technical regulation). These efforts also create demand for more diverse QI services in the metrology and conformity assessment area. As such, this sector offers promising ground for future QI interventions. In Morocco, the development of this sector is still in an early stage of development but shows large opportunities for the near future. Awareness in the private sector (and among consumers) could play an important role in creating demand for QI services. Needs assessment efforts may also be necessary to ensure that the right needs are covered early on and that coordination across stakeholders is ensured.

Solid waste management is a sector with high relevance across all three countries. Even if the organisation of the sector varies across countries (depending on the role of the informal sector, the degree of incineration, the type of waste, the recycling levels, the extent of landfills, etc.), some general challenges could be identified. The specific QI interventions would have to be customised to the country-context particularities. The most pressing issues

97 As a reminder, we did not examine this sector in India because there is extensive research already available and PTB is also already active in this area with Indian partners.

that this sector faces relate to improving the waste management organisation (i.e., collection and waste separation), developing procedures for recycling and reuse, and improving implementation capabilities. Technical regulation is considered necessary, especially for certain types of waste (e.g., hazardous waste) as well as metrology and conformity assessment capabilities relevant for waste characterisation and for soil, water, and air monitoring and site rehabilitation. Generally, however, awareness and training are also considered essential.

Sustainable transportation, especially given the increase in population and urbanisation levels in emerging and developing countries, has been identified as a priority sector in all three cases. The technology focus, however, varies. India, already having a strong automotive sector, is considering investing significantly in shifting to electric mobility, both in terms of domestic manufacturing (seeking to become globally competitive) as well as in terms of national urban mobility. Morocco's ambitions are relatively lower in this sector but are oriented in the same direction. In terms of manufacturing, Morocco's focus is on batteries for electric cars in the short term. The national strategy is mainly oriented towards switching public sector fleets to e-vehicles (cars and buses) and setting up networks of renewable energy power charging stations. It is in this area that most QI capabilities are expected to be needed. Ethiopia's focus is quite different; it is on rail-bound passenger and freight transportation. Given the early stage of this development and its reliance on foreign investment (and project developers), the most pressing needs relate to training and streamlining of QI services.

Water management related technologies, here explored only for the case of Morocco, are also important for most developing and emerging economies (as seen in Section 4.2). In the case of Morocco, we have seen that more standards may have to be adopted and testing facilities may be insufficient. For a country like Morocco that is under severe water stress, interventions in this area may be urgent and relatively less "demanding" given that existing capabilities already exist. Assessing the needs in terms of metrology and conformity assessment exactly may be necessary. Moreover, desalination will be increasingly used here (combined with renewable energy) and in other countries. Assessing the specific QI needs and the extent to which they may have to be provided locally is necessary.

Air pollution monitoring technologies, assessed in the case of India, are also relevant for most developing countries. Our findings point to promising opportunities for QI interventions (and collaboration) in this area, especially regarding conformity assessment for low-cost sensors and metrology. As local manufacturing for such technologies may also increase, QI services are expected to become increasingly relevant. Awareness, training, and implementation issues (as discussed above) are also highly relevant for this green technology sector.

Sustainable agriculture is a complex sector of critical importance for most developing countries. In the case of Ethiopia, we see that QI services are extensively needed in pre-production (seeds, fertilisers and pesticides), production (related to water, soil and pest management) and post-harvest (storage and processing). Essential QI interventions would be in strengthening the testing capacities for soil, seeds, livestock and agricultural products, for example. Input quality, in terms of compliance with various norms, and its assessment is very relevant in view of weak regulatory frameworks and low accountability. Similarly, QI infrastructure could focus on capacity development of farmers and other rural communities in value addition, thereby increasing their competitiveness.

Based on our analysis, Table 19 illustrates possible road maps for sector-level QI interventions for each case study country that takes into account both their national strategies for these sectors and their existing capabilities.

Table 19: Suggested road map for sector-level QI interventions

		Short term	Medium term	Long term
India	Air pollution monitoring			
	Energy efficiency in buildings			
	Solid waste management			
	Sustainable transportation			
Morocco	Renewable energy systems			
	Energy efficiency in buildings			
	Solid waste management			
	Water management			
	Sustainable transportation			
Ethiopia	Renewable energy systems			
	Solid waste management			
	Sustainable transportation			
	Sustainable agriculture			

Source: Authors

6 Key findings and implications for quality infrastructure in developing and emerging economies

The green transformation will lead to a range of new green technologies diffusing across emerging and developing countries at different speeds. Our study provides insights on this diffusion and its implications for the NQI system. Understanding what new QI services are needed and which of them need to be provided at the national level is essential for using green technologies efficiently and effectively, which in turn will help accelerate the green transformation.

6.1 Market trends and QI implications

Green technologies have seen fast rates of innovation between 1975 and 2017, especially after 2005. In fact, green patents grew at much faster rates than other technologies. Geographically, we observe increased global competition in green technology development, with several Asian countries (especially China, but also South Korea and Taiwan) becoming leaders in green innovation. Also, important to note, while OECD countries still lead in green innovation, some emerging economies have become increasingly active in technology development. China stands out in all technology areas, but especially in technologies related to electricity generation, sustainable agriculture,[98] energy efficiency and transportation. The green technology profiles of other emerging countries very much reflect their specific economic structure, specialisation and competitive advantage.

Combining patent analysis (the best available measure of past technology development trends) and the Delphi foresight assessment that revealed experts' perceptions of future market trends, we identify the most dynamic green technology trends. This includes some technologies whose patents have been registered years ago but that are expected to continue diffusing "rapidly" or a least "moderately" in the future: technologies related to renewable energy (especially solar PV, wind energy), sustainable transportation (e.g., hybrid vehicles, energy storage for electromobility), water management (e.g., wastewater treatment), sustainable agriculture, energy efficiency in buildings, and a range of enabling technologies for climate change mitigation, among others. For those technologies, QI service requirements are well known, although often still in short supply in developing and emerging economies. There is another group of more recent green technologies that includes more advanced renewable-energy-related technologies (e.g., smart grids, biofuels, fuel-cells), recycling, processing and waste separation, system integration related to power networks and ICT, among others. Anticipating the QI needs for this newer group is more challenging.

Technologies differ not only in terms of novelty, but also with regard to technological and QI sophistication (see Table 13). For instance, technologies such as recycling of paper, glass and aluminium and SWHs require a less

98 Specifically, adaptation technologies in agriculture, forestry, livestock and agroalimentary production.

sophisticated QI (see Table 15), whereas, for example, smart grids demand more comprehensive interventions across the entire NQI system.

6.2 Recommendations for QI development

- NQI institutions should invest more in technology foresight, market observation and QI needs assessments. A range of green technologies are now rapidly diffusing in developing and emerging countries and many require QI services that are not yet in place.
- NQI institutions should place emphasis on green technologies as these technologies have a dual benefit. QI services increase industrial efficiency, reduce transaction costs and investment risks, enable access to new markets, enhance competitiveness and promote consumer protection – this holds true both for green and non-green technologies; but green technologies have the additional advantage of contributing to the public good as they help reduce negative impacts on the local and global environment as well as on public health and thereby contribute to preserving sound ecological conditions for future generations. If NQI systems are not adapted quickly, countries risk investing in inappropriate technologies, leading to project failure and underperformance. Furthermore, the green transformation will be held back, with sometimes dire environmental consequences.
- Given the public goods character of a global green transformation, countries with advanced NQI systems should scale up investments in QI technology transfer and capacity building.
- Within the green technologies, there are good reasons to pay special attention to rapidly spreading technologies. Demand will quickly evolve in a variety of green technologies related to renewable energies and related technologies (energy storage, smart grids), in energy-saving, recycling and "circular" technologies, in low carbon mobility, water conservation and reuse technologies, and innovations for climate-smart agriculture (see, for example, Figures 9 and 11). As this scoping study can only show what experts perceive as diffusion trends, more detailed studies are needed to zoom into country-specific trends in these dynamic sectors.
- The increasing differentiation of technologies and the international orientation of conformity assessment providers (such as TÜV and SGS)

implies that countries often can (or must) use their services rather than develop capabilities locally. When it makes sense to have, for instance, a specific testing facility domestically and when it is more economical to use services provided by international agencies or locally operating project developers is not easy to decide. NQI systems therefore need to put more effort into understanding the economics of QI services, including "Make-or-Buy" decisions. This may require a shift of skills, for example, from engineering skills for running a test facility to managerial skills for running smart public tenders, and defining exactly which QI elements are important and how to elicit the best and lowest cost offer. This should also be reflected in the capacity-building offered by international development partners, such as PTB.

- NQI needs do vary according to techno-industrial ambitions. Therefore, development cooperation actors should systematically distinguish QI offers by strategic opportunities and constraints. The argument for having domestic test capacities in place is stronger when countries transition from being (green) technology buyers to manufacturers and developers of elements and systems. Whether this is economically viable depends on the strength of the national innovation systems, the size of the markets and the specific green technology. The majority of developing countries will probably not meet the conditions for venturing into green manufacturing at scale, at least in the short run. While some elements of green technologies may be seen as globally traded commodities, others may involve local manufacturers who also adapt them to local conditions. In these cases, close interaction between local producers and NQI institutions will be necessary and thus, services need to be customised and provided locally.
- International EPC companies often play an important role in implementing large-scale green technology projects, especially in the renewable energy field. NQI institutions may benefit from partnering with these project developers. This could lead to win-win situations in which project implementation is made more failure-proof and capacities in NQI institutions are built up.
- Policy makers should systematically assess political interests and related risks when helping to set up national laboratories and establishing NQI systems. QI stakeholders may wish to have a range of sophisticated facilities and a mandate to run a wide range of conformity assessments,

even when there is little demand for such services, while customers still prefer international services (because their certificates are recognised abroad). In the worst case, this may lead to situations where customers are obliged to make use of inappropriate services and QI services may be abused for rent-seeking. Introducing performance criteria, such as customer satisfaction ratings and cost-coverage of services, may reduce such risks.

- NQI systems are often not well integrated, for example, there is little cooperation across the "pillars" of the system. System integration should, therefore, be emphasised to avoid situations in which the weakest link in the system hinders the deployment of new green technologies. This does not necessarily imply the need to build "complete" NQI systems (with all components formally in place and nationally owned) for every technology. The objective should be to aim for "smart" systems that ensure national capacities where they are needed but are also able to make intelligent use of international systems.

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Annexes

Appendix

Table A1: CPC-selected codes in the Y class of green technology patents

CPC Code	Name of the class
Y02A20/10	Relating to general water supply, e.g., municipal or domestic water supply
Y02A20/20	Water pollution control technologies
Y02A20/30	Relating to industrial water supply, e.g., used for cooling
Y02A20/40	Water resources protection or enhancement
Y02A40/	Adaptation technologies in agriculture, forestry, livestock or agroalimentary production
Y02B10/	Integration of renewable energy sources in buildings
Y02B20/	Energy efficient lighting technologies
Y02B30/	Energy efficient heating, ventilation or air conditioning (HVAC)
Y02B40/	Technologies aiming at improving the efficiency of home appliances
Y02B70/	Technologies for an efficient end-user side electric power management and consumption
Y02B80/	Architectural or constructional elements improving the thermal performance of buildings
Y02B90/	Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation
Y02C10/	CO_2 capture or storage
Y02D10/	Energy efficient computing
Y02D30/	High-level techniques for reducing energy consumption in communication networks
Y02D50/	Techniques for reducing energy consumption in wire-line communication networks
Y02D70/	Techniques for reducing energy consumption in wireless communication networks
Y02E10/10	Geothermal energy
Y02E10/20	Hydroenergy
Y02E10/30	Marine energy

Table A1 (cont.):	CPC-selected codes in the Y class of green technology patents
Y02E10/40	Solar thermal energy
Y02E10/50	Solar photovoltaic (PV) energy
Y02E10/60	Solar thermal-PV hybrids
Y02E20/10	Technologies for improved output efficiency
Y02E40/70	Smart grids
Y02E50/10	Biofuels
Y02E50/30	Fuels from waste
Y02E60/10	Energy storage
Y02E60/30	Hydrogen technology
Y02E60/50	Fuel cells
Y02E60/70	Smart grids in the energy sector
Y02P60/	Technologies relating to agriculture, livestock or agroalimentary industries
Y02P70/	Climate change mitigation technologies in the production process for final industrial or consumer products
Y02P80/	Climate change mitigation technologies for sector-wide applications
Y02P90/	Enabling technologies with a potential contribution to greenhouse gas (GHG) emissions mitigation
Y02T10/10	Conventional vehicles (ICE)
Y02T10/62	Hybrid vehicles
Y02T10/64	Electric machines technology for application in electromobility
Y02T10/70	Energy storage for electromobility
Y02T10/72	Electric energy management in electromobility
Y02T10/80	Technologies aiming to reduce GHG emissions common to all road transportation technologies
Y02T10/90	Energy efficient charging or discharging systems for batteries, ultracapacitors, supercapacitors or double-layer capacitors specially adapted for vehicles
Y02T90/	Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation

Table A1 (cont.): CPC-selected codes in the Y class of green technology patents	
Y02W10/	Technologies for wastewater treatment
Y02W30/10	Technologies related to waste collection, transportation, transfer or storage, e.g., segregated refuse collecting, electric or hybrid propulsion
Y02W30/20	Technologies related to waste processing or separation
Y02W30/30	Landfill technologies aiming to mitigate methane emissions
Y02W30/40	Bio-organic fraction processing; production of fertilisers from the organic fraction of waste or refuse
Y02W30/50	Reuse, recycling or recovery technologies
Y02W30/52	Dismantling or mechanical processing of waste for the recovery of materials during separation, disassembly, pre-processing or upgrading
Y02W30/60	Glass recycling
Y02W30/62	Plastics recycling
Y02W30/82	Recycling of waste of electrical or electronic equipment
Y02W30/84	Recycling of batteries
Y02W30/90	Reuse, recycling or recovery technologies cross-cutting to different types of waste
Y04S40/	Systems for electrical power generation, transmission, distribution or end-user application management characterised by the use of communication or information technologies, or communication or information technology specific aspects supporting them
Y04S50/	Market activities related to the operation of systems integrating technologies related to power network operation or related to communication or information technologies
Source: Authors	

Table A2: Technology survey – Delphi survey, Round 2
Part I: Feedback initial results and elicit further comments.
Q1. The table below synthesises responses to the question: *"Do you expect that, by 2030, markets (for the specific technology) will develop slowly, moderately, or rapidly in emerging and developing countries?"* Do you think the figure provides a good approximation of expected green technology market trends? Agree Disagree Cannot assess Please comment: ______________ **Q1.1 For the technologies you are familiar with, do you see the need for further refinement or modification?** Yes No If "yes", please explain for which technologies, and what kind of refinement or modification is required:__________________
Q2. The figure below synthesises responses to the question: *"How do you rate the degree of sophistication of the related technologies? Low, medium or high?"* Do you think the graph provides a good approximation of the degree of sophistication of related technologies? Agree Disagree Cannot assess Please comment: ______________
Q2.1. For the technologies you are familiar with, do you see the need for further refinement or modification? Yes No If "yes", please explain for which technologies, and what kind of refinement or modification is required: __________________
Q3. The table below synthesises responses to the question: *"Do you expect that, by 2030, (for the specific technology), developing countries will provide little (<30 per cent), medium (30-70 per cent) or high (>70 per cent) locally added value and technological capabilities?"* Do you think the table provides a good approximation of these expected future developments? Agree Disagree Cannot assess Please comment: ______________

Table A2 (cont.): Technology survey – Delphi survey, Round 2

Part II: Open questions

Q1. Market development of green technologies often depends on regulatory changes (e.g., renewable energy feed-in-tariffs to boost technology diffusion). In which technology areas do you expect a **substantial regulatory push towards greener practices** in emerging/developing economies? Please select:
– recycling
– water saving
– wastewater treatment
– energy efficiency in buildings
– electricity generation
– agriculture
– transportation
– other (please specify and explain) ________________________

Q2. Assessments of green technology (including our survey) may have a hardware bias: When thinking about sophistication and the potential for indigenous capabilities and value creation in developing countries, people may mainly refer to manufacturing of products and parts. Yet the main business potentials may be in creating financial models, developing software, adapting concepts (e.g., new waste collection or traffic solutions operation and maintenance).
Do you agree with this statement: **"The potential for domestic value addition in developing and emerging economies will increasingly lie in services rather than manufacturing."**
Agree Disagree
Explain: __________________
Can you refer us to interesting country cases? ___________________________
Q3. Decarbonisation scenarios suggest that it is almost impossible to reduce GHG at the scale needed to stay below 2o Celsius global warming (let alone 1.5o) without carbon capture, utilisation and storage (CCUS) technologies. Yet in our expert survey, **CCUS is not seen as a rapidly diffusing technology**. How do you explain this tension? _________________________

Q4. Many observers assume that developing/emerging economies will largely be adopters of imported green technologies, with learning processes limited to selecting appropriate technologies and new-to-the-firm/to-the-country innovations.
Do you see any **potential for new-to-the-world innovations emerging** in developing/emerging economies? Please specify and explain:
____
Can you refer us to interesting country cases? ____________________________

Table A2 (cont.): Technology survey – Delphi survey, Round 2
Q5. Technologies related to **wastewater treatment** are expected to **diffuse slowly by 2030** in developing countries, although **value added and domestic capabilities are high** in this sector. Why do you think this is the case? ________________ What can be done to accelerate diffusion of these technologies in developing countries? _ ______________________
Q6. The **recycling** (of paper, glass, aluminium and some form of e-waste recycling) sector is **expected to develop rapidly** in developing countries, but only **little value added and domestic capabilities** are expected to be created by 2030. Why do you think this is case? ________________________________ In which activities/technologies/processes could value added be increased and learning accelerated? __________________________ What could be done to achieve this? ________________
Q7. Most technologies related to **energy efficiency in buildings** are expected to **diffuse rapidly** in developing countries by 2030, but only **limited (or moderate) level of value added and domestic capabilities** are expected to be provided. Why do you think this is the case? In which activities/technologies/processes could value added be increased and learning accelerated? __________________________ What could be done to achieve this? ________________
Q8. In many of your comments in the earlier survey, **China is seen as a strong outlier among emerging economies** – a country with accelerated diffusion of many green technologies and at the same time high levels of value addition and capability building in sophisticated technologies. Do you observe particularly dynamic developments in specific technology fields in other emerging economies? Please specify and explain: _____________
Source: Authors

Table A3: List of interviewed organisations	
Name	**Sector**
Morocco (November 2018)	
LPEE	Quality infrastructure
IMANOR	Quality infrastructure
MIICEN	Government agency
AMEE	Government agency
4C Maroc	Government agency
Ministry of Sustainable Development	Government agency
MASEN	Quasi-public agency
Conseil Economique Social et Environnemental	Education and research
IRESEN	Education and research
ENIM	Education and research
Ecole Hassania des Travaux Publics	Education and research
Université Ibn Tofail - Kenitra	Education and research
CGEM’s Commission nouvelle économie climat	Private sector
Nareva	Private sector
TÜV Maroc	Private sector
Cluster Solaire	Private sector
KfW Bankengruppe	International cooperation
GIZ	International cooperation
Ribat Al Fath, Club de l’Environnement	NGO
India (March 2019)	
QCI	Quality infrastructure
NABCB	Quality infrastructure
NPL	Quality infrastructure
BIS	Quality infrastructure
NABL	Quality infrastructure
BEE	Government agency

Table A3 (cont.): List of interviewed organisations	
Ministry of Environment, Forest and Climate Change	Government agency
EESL	Government agency
CEEW	Education and research
Global Green Growth Institute, India	Education and research
TERI	Education and research
Shakti Foundation	Education and research
NEERI	Education and research
CII	Private sector
ACMA	Private sector
Breathe Easy	Private sector
SECI	Private sector
E3 Waste Solutions	Private sector
BSES Yamura Power Limited	Private sector
Smart Joules	Private sector
EDS	Private sector
Conserve India	Private sector
KfW Bankengruppe	International cooperation
GIZ, Energy efficiency building programme & Indo German energy programme	International cooperation
Toxics Link	NGO
The Climate Group	NGO
Ethiopia (March-April 2019)	
ESA	Quality infrastructure
ATA	Government agency
EEP	Government agency
Ethiopian Energy Authority	Government agency
Ministry of Innovation and Technology	Government agency
MoWIE	Government agency

Table A3 (cont.): List of interviewed organisations	
MoEFCC	Government agency
Technology and Innovation Institute	Government agency
ERC	Government agency
Policy Studies Institute	Education and research
Ethiopian Agricultural Research Institute	Education and research
Global Green Growth Institute, Ethiopia	Education and research
GIZ	International cooperation
General, technology-related	
NILU	Education and research
Kassel University	Education and research
Fraunhofer Institute	Education and research
PTB	International cooperation
Source: Authors	

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