Variable renewable energy policy impact forecast tool

Technical documentation (DRAFT)

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1 Introduction

The renewable policy impact forecast tool presented and described in this document aims to supplement the renewable energy guidance document developed under the Initiative for Climate Action Transparency (ICAT, 2018) and other efforts worldwide to assess greenhouse gas (GHG) impacts of renewable energy policies. This shell tool allows for the forecast the share of variable renewable energy (VRE) from total generation based on a country's VRE policy package based on a s-curve modelling logic.

The tool developed in this project focuses on solar (including both photovoltaic (PV) and solar thermal) and wind power technologies. Both technologies experienced considerable growth rates worldwide in recent years (REN21, 2018) and have been declared by some as the "winner" of the energy transition (Agora Energiewende, 2013). Therefore, the ongoing capacity expansion of these variable renewable technologies is crucial to significantly increase the share of variable renewables in total electricity generation.

The tool is developed based on:

- the analysis carried out by Climact and NewClimate Institute (Cornet *et al.*, 2018), which developed a tool to forecast future renewable electricity deployment for the European Union (EU) up to 2030 based on an adequacy assessment of a current renewable energy policy package linked to an "s-shaped" technology diffusion curve, and
- the idea presented in Boie, Ragwitz and Held (2016), in which future diffusion of renewable electricity generation technologies in Germany was forecast for 2015–2018 based on a composite indicator covering economic and non-economic diffusion factors.

In this project we developed a framework that can be applied to a wider range of countries and create a mid-term forecast up to 2030. The tool includes default policy assessment data for G20 countries (excl. the European Union), while at the same time allowing users to carry out their own policy assessment to forecast renewable electricity deployment for a country of interest. The uniqueness of this type of tools is that it enables to capture what key actors (e.g. policy makers, investors, and academics) see as major determinants for renewable energy diffusion based on their experience and research in a transparent manner, and translate them into future diffusion projections (Boie, Ragwitz and Held, 2016).

This document contains the documentation of the tool and its assumptions. It is structured around the following sections:

- **Section 2** provides the methodological framework (incl. the rationale of s-curves in technology diffusion forecasting, the mathematical model used, the policy package covered, and the translation of the policy package to Variable Renewable Energies share forecast),
- **Section 3** provides an overview and description on how the excel tool is set up,
- **Section 4** provides the tool's results for G20 countries (excl. the European Union), and
- **Section 5** mentions the limitations of the tool.

2 Methodological framework

The renewable policy assessment tool developed in this project comprises of three components (Figure 1):

1) Development of a renewable technology diffusion model
2) Development of a renewable energy policy package assessment framework
3) Linkage between the policy package assessment outcomes and the technology diffusion model

In the following sections, we describe these three components in detail.

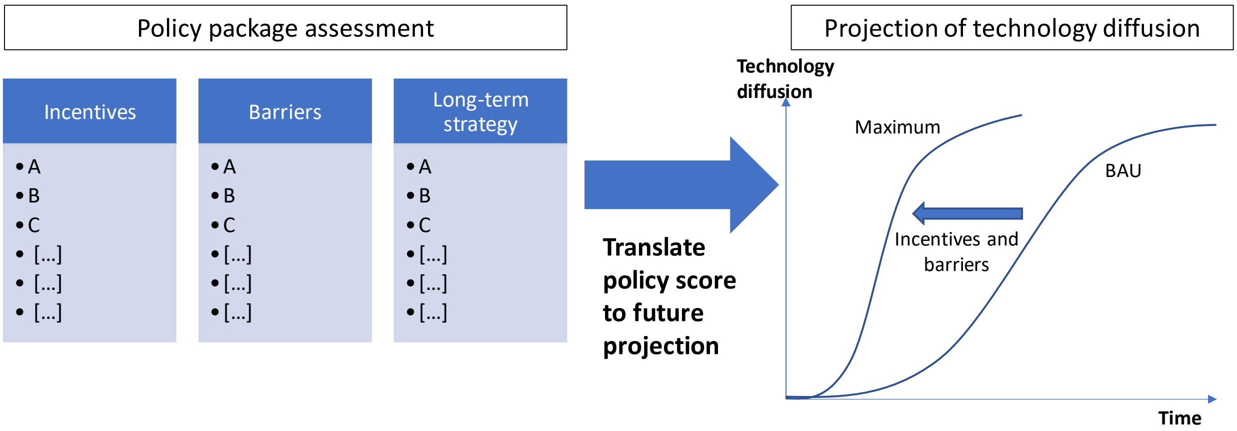

Figure 1: Overview of the tool components

2.1 Renewable technology diffusion model

2.1.1 Technology diffusion background

Technology diffusion has been studied in the context of innovation theory since the 1930s (Greenacre, Gross and Speirs, 2012). In the model of innovation from Schumpeter ((1934) as cited by (Greenacre, Gross and Speirs, 2012)), diffusion—the spreading of the technology or process in the market—is represented by an s-shaped curve, where take-off starts slow, followed by rapid diffusion that then slows down as saturation is reached. Rogers (1971) also describes the rate of adoption of a technology—the relative speed by which an innovation is adopted by members of a social system—with an s-curve when plotting the cumulative number of adopters over time.

Historically, the s-curve (or logistic) market penetration pattern has been observed for different technologies, from diesel cars (Cames and Helmers, 2013; Roedenbeck and Strobel, 2014; ACEA, 2015), to energy transitions and technological substitution (Packey, 1993; Grübler, Nakicenovic and Victor, 1999; Kucharavy and De Guio, 2011). On this premise, several studies have modelled possible future deployment of renewable energy technologies using a logistic growth model (Rao and Kishore, 2010; Wilson, 2012; Davidsson *et al.*, 2014; Boie, Ragwitz and Held, 2016).

Kucharavy and De Guio (2011) identified that although most studies on technological change are based on the application of logistic curves and s-curves, not all s-shaped curves are the same. These logistic functions can be classified into simple and complex depending on whether they are symmetric or not. The same authors state—based on conclusions of numerous publications—that complex logistic models have limited application and low efficacy for technology forecasts (Kucharavy and De Guio, 2011) and can be considered as “overengineering” the problem, given the large degree of uncertainty that persist with developing any forecast. Based on this insight this study applies a simple s-curve/logistic diffusion model.

2.1.2 Selection of a technology diffusion indicator

Studies on renewable energy (RE) technology diffusion use different model variables. While some focus on the modelling of cumulative or installed capacity over time (Carolin Mabel and Fernandez, 2008; Changliang and Zhanfeng, 2009; Wilson, 2012; Davidsson *et al.*, 2014; van Sluisveld *et al.*, 2015; Hansen, Narbel and Aksnes, 2017), others model performance over time, i.e. by plotting investment in R&D, patent application or product sales as proxies (Nieto, Lopéz and Cruz, 1998; Dubarić *et al.*, 2011), cumulative adoption or market penetration of a technology over time (Boie, Ragwitz and Held, 2016), or electricity generation over time (Doner, 2007; Rypdal, 2017).

As depicted by Grübler, Nakicenovic and Victor (1999), technological diffusion—and substitution—follow an s-curve when the fraction of a useful product or service, such as electricity, supplied by each major competing technology, such as wind or solar, is plotted over time. Moreover, Rypdal (2017) argues that electricity consumption over time better represents the growth of renewable energy technologies, as unlike other variables (i.e. cumulative capacity), this variable "*also reflects the growth of implementation of technologies that improve the utilisation of the installed capacity… which includes improvements and expansion of electric grids and better system integration of intermittent power sources*" (p.9). Based on these premises, we chose to forecast the share of variable renewable energy generation as the variable changing over time.

The simple s-curve equation used in this study is the following:

$$S(t) = \frac{A}{1 + \exp(-B * t)}$$

Equation 1

where $S(t)$ is the share of variable renewables (VRE; i.e., wind and solar) over time, A is the ceiling or maximum share of VRE in a country, B is the pace of growth depicting how fast the VRE share increases over time, and t is the time in years.

2.2 Translating policy package assessment results to technology diffusion forecast model

In this tool the projection of variable renewables under current policies (hereinafter, "current policy curve") is developed using the following two steps

1. **Definition of a "good practice" curve and a "no policy" curve**. These two curves represent the high (good practice) and low (no policy) boundaries of a country's future VRE development under current policies. Both these curves are s-curves defined by pace of growth (B) and ceiling (A) variables (as shown in Equation 1). Details of how these two curves are defined can be found in the next paragraphs.
2. **Definition of the factor "driving the pace of growth" ($\boldsymbol{F_g}$) and the factor "defining the ceiling" ($\boldsymbol{F_c}$).** These two factors are the means by which a country's policy package on variable renewable energy is translated to an s-curve between the good practice and the no policy curves (see Figure 2). These factors have values between 0% and 100%, as the assessment of the policy package is normalized between the maximum and minimum values from the good

practice and no policy curves, respectively. The detailed process for the estimation of these factors is specified below under “current policy” curve.

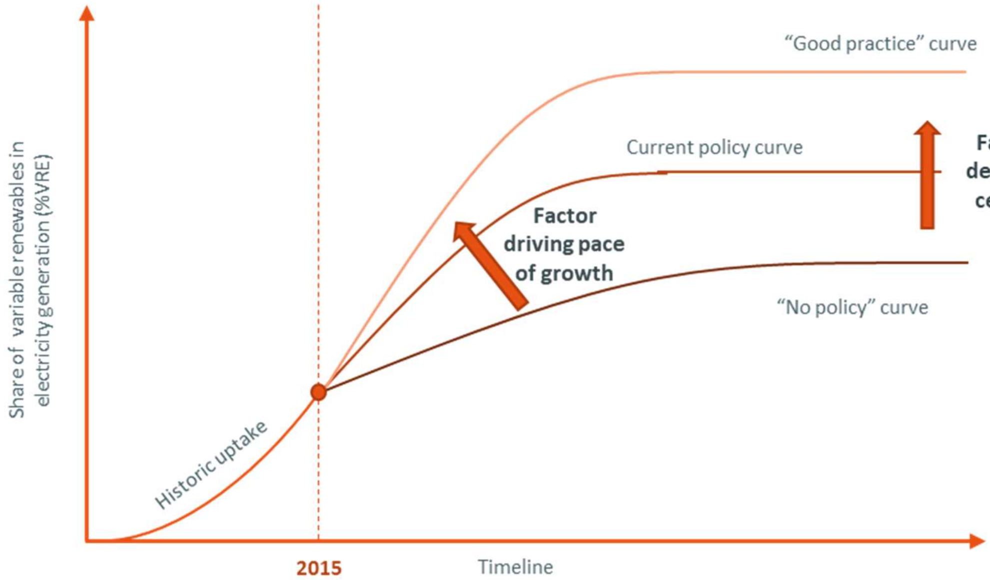

Figure 2. Schematic of a country’s VRE electricity generation share development over time based on the relationship between a “good practice”, “no policy” and “current policy” s-curves.

For historical years we use data from IEA (IEA, 2018a) balances to estimate the %VRE in total electricity production. We consider historical data until 2015.

The following sections describe the definition and the development of the good practice and no policy curves, and how the policy package assessment scores are translated into an s-curve model to develop a current policy curve.

2.2.1 “Good practice” curve

The good practice curve defines the upper bound of a potential variable renewable uptake (in terms of share of total electricity generation). As shown in the mathematical model (see Equation 1), this s-curve is defined in terms of a pace of growth (B) and a ceiling (A) factor. The good practice curve represents growth fitted to the fastest sustained growing share of renewables in total electricity generation in a country and the maximum possible VRE share in the same country.

2.2.1.1 Pace of growth – of a good practice curve

The good practice curve in this study is based on the observed growth in variable renewables in total electricity generation in Denmark between 1995 and 2015, which went from 3.2% in 1995 to 50.9% in 2015. Based on this, the pace of growth was estimated using the following equation:

$$B = \frac{\ln\frac{1}{S(t_1)-1} - \ln\frac{1}{S(t_2)-1}}{t_2 - t_1} \qquad \text{Equation 2}$$

where: B is the pace of growth of VRE share, t_1=1995, t_2=2015 and $S(t_1)$ and $S(t_2)$ are the shares of variable renewables in the corresponding years.

Figure 3 shows the ideal s-curve for Denmark (using Equation 1 with the estimated pace of growth shown in Equation 2 and Denmark's historical VRE share development). For this curve, the saturation period (i.e. the time it takes to go from 1% to 99% VRE share) is 53 years.

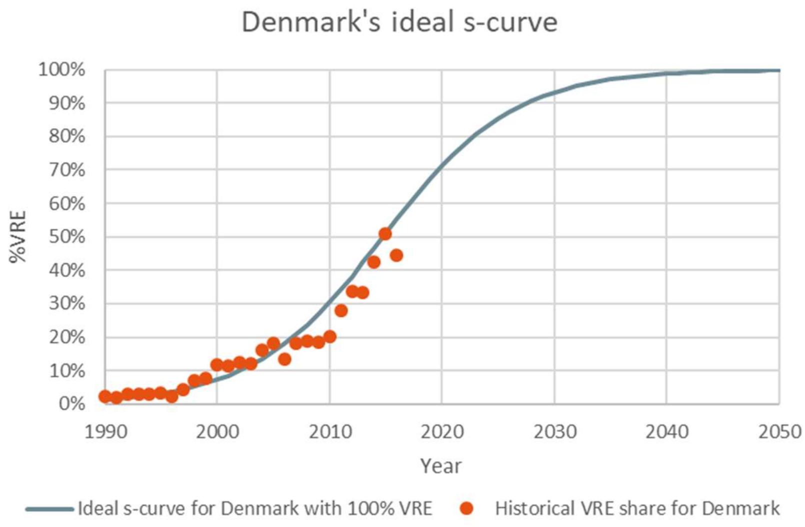

Figure 3. Denmark's historical developments of VRE share over time (IEA, 2018a), and its ideal s-curve based on historical growth and assuming a hypothetical VRE ceiling of 100%.

2.2.1.2 *Ceiling (or long-term potential of VRE share) – of a good practice curve*

In a decarbonised power sector, the maximum share of variable renewables (i.e. solar and wind) in a country could be 100%, as countries like Denmark aim to achieve. However, in reality, other low-carbon technologies (including hydro, geothermal, ocean, biomass, CCS and nuclear) are likely to play a role in this sector's decarbonisation (Teske, Sawyer and Schäfer, 2015; Blok, Van Exter and Terlouw, 2018; IRENA, 2018a). While the projected energy mix significantly varies in the literature of energy sector decarbonisation, studies on highly ambitious decarbonisation scenarios agree that a decarbonised power sector is dominated by renewable electricity production. These sources also agree that the share of variable renewables is not likely to reach 100% on both regional and global levels. Some examples of these scenarios include Greenpeace's Energy [RE]volution scenario (Teske, Sawyer and Schäfer, 2015), which assumes 100% renewables in 2050, Blok et al. (2018), which present an approach for 100% decarbonisation of the global energy system by 2050, or IRENA's REmap case 2050 scenario (IRENA, 2018a), which is aligned to keeping global temperature increase to below 2°C by 2100.

Based on the scenarios from the aforementioned studies, we have defined the long-term potential, or the "ceiling" of the VRE share in total electricity generation under the "good practice" curve at 70% by default, but with the option to adapt this setting based on country and region-specific circumstances. These include the existence of other renewables (especially dispatchable ones such as hydro, biomass and to some degree geothermal) in the system today as well as their future potential, preferences for the use of nuclear energy, wind/ solar resource and load matching, etc

2.2.2 "No policy" curve

The "no policy" curve defines the lower bound of the potential variable renewables uptake. It represents a scenario under which VRE diffusion is achieved without the help of policies, meaning that VRE growth would only be driven by market and technology development. Similar to the "good practice curve", we have looked at literature focusing on the future of the global energy system to estimate the ceiling and pace of growth factors for this curve.

2.2.2.1 Ceiling (or long-term potential of VRE share) of a no policy curve

On the ceiling, we have focused on projected VRE share in reference and business-as-usual scenarios including IRENA's Reference Case[1] (IRENA, 2018a), BP's Evolving Transition scenario (ET)[2] (BP Energy Economics, 2018), and IEA's WEO Current Policies Scenario (CPS)[3] (IEA, 2018b). Based on the projections for 2040 or 2050 from these scenarios, which take into account existing and some planned policies but not long-term targets or strategies, we define the ceiling of the "no policy" curve as 30% VRE.

2.2.2.2 Pace of growth of a no policy curve

For the pace of growth—and based on expert judgement—we assume that VRE share growth will take three times longer as our "good policy" curve if no policies are implemented. We were not able to find literature to support this as all of the above-mentioned scenarios do not supply the time horizons needed to define a saturation period of around 150 years.

2.2.3 "Current policy" curve

Our forecast of a country's VRE share development over time lies on the premise that a country's "current policy" curve will lie between the "good policy" and "no policy" curves depending on its VRE policy package. As for the other two s-curves (i.e. "good practice" and "no policy"), the "current policy" curve is modelled based on the ceiling (A) and pace of growth (B) variables (see Equation 1). The variables for this curve are numbers between the values used in the good practice and no policy curves, which are estimated though the *factor driving the pace of growth* (F_g) and the *factor defining the ceiling* (F_c) for a given country. These factors are defined as values between 0% and 100%, which result from normalizing the assessment of each of the drivers and barriers to VRE deployment in the policy package.

After a review and selection of the policies relevant to a country's VRE development (please refer to Section 2.3 for a comprehensive explanation of the policy package used in this study), we categorise each of the policies as affecting the ceiling (A) or affecting the pace of growth (B) of VRE development. We then calculate the *factor driving the pace of growth* (F_g) and the *factor defining the ceiling* (F_c) for a given country.

2.2.3.1 Factor defining the ceiling (F_c)

The *factor defining the ceiling* (F_c) determines the upper maximum level (i.e., level of saturation) of variable renewables integration that can be achieved in the long-run with the current policy package in place. This factor depends on a number of drivers that determine how much VRE can be integrated into the system at any point in time (see Section 2.3 for a full overview of policies affecting this factor).

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[1] "This scenario takes into account the current and planned policies of countries. It includes commitments made in NDCs and other planned targets. It presents a "business-as-usual" perspective, based on governments' current projections and energy plans" (IRENA, 2018a).

[2] This scenario is the "assumes that government policies, technology and social preferences continue to evolve in a manner and speed seen over the recent past" (BP Energy Economics, 2018).

[3] "The Current Policies Scenario (CPS) considers the impact of only those policies and measures that are firmly enshrined in legislation as of mid-2018. In addition, where existing policies target a range of outcomes, it is assumed that the lower end of the range is achieved" (IEA, 2018b).

2.2.3.2 Factor defining the pace of growth (F_g)

The *factor driving the pace of growth* (F_g) determines how fast the share of variable renewables in total electricity generation increases over time. The pace with which the rate of variable renewable electricity generation grows is driven by the extent and effectiveness of the support in place in the country (policy drivers), but can also be reduced by barriers (see Section 2.3 for a full overview of policies and barriers affecting the pace of growth factor).

While we distinguish between the factor affecting the ceiling (F_c) and the factor affecting the pace of growth (F_g), it should be noted that the former also indirectly influences the pace of the forecasted growth in VRE share; F_c affects A in Equation 1, meaning that F_C is a multiplication factor on the entire diffusion curve.

A graphic depiction of the assessment logic can be found in Figure 2. If both the ceiling and pace of growth factors were 0%, the currently policy curve would equal the “no policy” curve. Vice versa, a value of 100% for both factors results in a curve that coincides with the “good practice” curve. While working together (only if both are 100% one will be able to reach the “good practice” curve) they shift the curve in different manners. How they shift the curve and why is described in detail in the next chapter.

Each of the factors consists of a set of measurable drivers that were found to influence the speed of uptake and saturation level of variable renewables in total electricity generation. The selection of drivers and aggregated quantification for both factors is explained in the following section.

2.3 Policy assessment framework: an overview

Both Climact and NewClimate Institute (Cornet *et al.*, 2018), and Boie et al. (2016) developed an extensive list of sub-indicators for developing a composite policy indicator for their focus countries. To be able to apply the analytical framework to G20 members and beyond, where the data availability varies substantially between members, an adaptation of the sub-indicator list was necessary.

We based the tool developed in this project (see Table 1 and Table 2 for an overview of indicators) largely on the assessment framework of the Allianz Climate and Energy Monitor (NewClimate Institute, Germanwatch and Allianz SE, 2018b, 2018a), which assessed the need and attractiveness of investments in solar and wind power technologies in G20 countries. We further considered the findings from the recent panel data studies that investigated the correlations between policies and renewable energy deployment (Aguirre and Ibikunle, 2014; Polzin *et al.*, 2015; Baldwin *et al.*, 2017; Carley *et al.*, 2017), review studies on the challenges towards large scale integration of VRE (Lund *et al.*, 2015; Hu, Harmsen, Crijns-Graus and Worrell, 2018; Hu, Harmsen, Crijns-Graus, Worrell, *et al.*, 2018) as well as policy studies from the International Renewable Energy Agency (IRENA, 2018b). The rationale for the selection of policy indicators can be found in Annex I.

The policy indicators are distinguished between those that affect both the long-term ceiling and the pace of growth of the VRE diffusion – presented in terms of percentage in total electricity generation – (presented in Table 1) and those that only affect the pace of growth of VRE diffusion (presented in Table 2). The former considers mainly long-term policy strategies for energy system transition, including factors such as infrastructure development and fundamental reduction in energy consumption – the latter focuses mainly on short- to mid-term policies for variable renewables.

The (sub-)indicators for each of the factors (and barriers) are quantified in a specific metric M, and normalized between the “good practice” (i.e. upper bound M_u) and “no policy” values (i.e. lower bound M_l). We estimate a ratio R_n based on the following equation:

$$R_n(\%) = \frac{M_n - M_l}{M_u - M_l} * 100$$

Equation 3

In cases where $M_n \leq M_l$ or $M_n \geq M_u$, the value of R_n remains 0% and 100%, respectively.

To estimate the weighted average of the factors (F_i) (i.e. factor defining the ceiling, factor defining pace of growth), we multiply each (sub-)indicators ratio by a weight w, and then divide by the total. For each of the factors we apply the following equation:

$$F_i = \frac{\sum_{n=1}^{N} R_n \cdot w_n}{\sum_{n=1}^{N} w_n}$$

Equation 4

where N is the number of (sub-)indicators aggregated into the factor F_i is either the factor defining the ceiling (F_c), or the factor defining the pace of growth (F_g),

To estimate the weighted average of the barriers (B_i) (i.e. pace of growth barrier and optional barrier), we multiply each driver's ratio by a weight w, and then divide by the total. For each of the barriers we apply the following equation:

$$B_i = \frac{\sum_{n=1}^{N} R_n \cdot w_n}{\sum_{n=1}^{N} w_n}$$

Equation 5

where N is the number of (sub-)indicators aggregated into the barrier B_i is the pace of growth barrier $(B_g\ )$ or the optional barrier.

Given that we have considered both drivers and barriers affecting the pace of growth, we have estimated an overall pace of growth factor F_G based on the following equation:

$$\mathrm{F_G} = F_g * (1 - B_g)$$

Equation 6

where F_g is the factor defining the pace of growth and B_g the pace of growth barrier.

For each policy (sub-)indicator (or driver), a weighting factor was given to reflect relative importance of the indicator compared to other policy indicators. The setting of weighting factors are based on NewClimate Institute experts' judgments, partially based on the knowledge obtained and feedback provided through the Allianz Climate and Energy Monitor project (NewClimate Institute, Germanwatch and Allianz SE, 2018b) and the EU renewable policy assessment project (Cornet *et al.*, 2018) – which included expert assessments from various sectoral experts involved in the project.

Table 1: Overview of policy indicators affecting the long-term potential ("ceiling") and pace of growth of VRE deployment in terms of share in total electricity generation

Indicator M	**Default weight** w	**Scoring**	**Data sources**
Long-term vision and strategic policies toward energy system transition	34%		
Long-term transition plan for the electricity system		[0,25,50,75,100] 100: A binding, ambitious and concrete strategy for the energy sector decarbonisation exists 75: A binding and ambitious long-term transition strategy exists but lacks concreteness 50: A binding strategy in place but lacks both ambition and concreteness 25: No 2050 plan but a post-2020 RE strategy exists 0: Policy cliff-edge after 2020 (RE strategy) The score is halved when there is no concrete strategy to reduce electricity demand consistent with the power sector decarbonisation "Binding": Submitted mid-century strategies to UNFCCC complemented with national information "Ambitious": full-decarbonisation of the power sector mentioned in the strategy "Concreteness": sector roll-out, intermediate targets, concrete ideas to implement plan, etc	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:1.1
Long-term renewable electricity target ambition		[0 to 100] 100: Target on trajectory towards 100% renewables in 2050 1-99: Linearly scaled between 100 and 0 0: Equal or lower than reference development of 1% increase per year or no target	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:1.2
System integration: non-market measures	33%		
VRE in grid codes		[0,100] 100: Yes, VRE are included in existing grid codes and/ or separate grid codes for VRE exist 0: No, VRE are not included in existing grid codes and/ or separate grid codes for VRE do not exist	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:3.1

Indicator M	Default weight w	Scoring	Data sources
Support schemes for demand-side management (DSM)		[0,50,100] 100: Both market-based and regulatory DSM policies are present 50: Only market or regulatory DSM policies are present 0: No policy present - *Market-based DSM policies* refer to dynamic power pricing policies which aim to shift and/or shape energy use of end-users (e.g. time-of-use pricing). - *Regulatory DSM policies* refer to two types of policies: 1) Utility obligations/energy efficiency obligations referring to schemes setting energy saving obligations/quantitative targets for energy distributors and/or retail energy sales companies and possibly coupled with a trading system (e.g. tradable white certificates, trading of eligible measures without formal certification, or trading of obligations). 2) Smart meter roll-outs under a policy mandate. Examples of policies include:Time-of-use tariffs in Brazil (Ferreira *et al.*, 2013), payment-based demand response and a price-based demand response in China (Warren, 2017)	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:3.3
Storage promotion & flexible supply-side policies		[0,100] 100: Yes 0: No “Yes” indicates that a national policy, roadmap, strategic plan or guidance on the promotion of energy storage exists and has been (at least partially) implemented. Examples of policies considered include: subsidies for stationary lithium-ion batteries in Japan (Tomita, 2014), US FERC Order No. 792 (2013), which includes improvement of the legal status of energy storage and streamlined procedures, and the UK’s Smart Systems and Flexibility Plan (UK Department for Business Energy & Industical Strategy and Ofgem, 2017; Cooke, 2018)	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:3.2
System integration: market measures	33%	[0,50,100] 100: Flexible markets AND capacity mechanism 50: Flexible markets OR capacity mechanism 0: None	(Veselov *et al.*, 2008; De Souza and Legey, 2008; Maloney, 2013; Pineau, 2013; The World Bank, 2015; Bose, Gupta and Kumar, 2015; Energienet DK, 2015; *REPORT ELECTRICITY MARKET REFORM IN SOUTHERN AFRICA*, 2016; Market Observatory for Energy of the European Commission, 2016; Milligan and Madan, 2016; pwc,

Indicator M	Default weight w	Scoring	Data sources
			2016; U.S. Trade and Development Agency, 2016; Vanadzina and Gore, 2016; FUNDACION DE INVESTIGACIONES ECONOMICAS LATINOAMERICANAS, 2017; Herbert Smith Freehills, 2017; Rioux *et al.*, 2017; Saddler, 2017; Wafa, 2017; Yu *et al.*, 2017; Botterud, 2017; Alberta Government, 2018; export.gov, 2018; Paik, 2018; Pamuk, 2018; Australian Government Department of the Environment and Energy, 2018; Shah, 2018; AutoGrid, 2018; Climate Policy Initiative, 2018; Demirkan, Ildiri and Mercan, 2018)

Table 2: Overview of policy indicators affecting speed of VRE deployment in terms of share in total electricity generation

Indicator M	Default weight w	Scoring	Data source
Mid-term strategic policies toward energy system transition	20%		
Mid-term RE target ambition		[Relative scoring between 0 and 100] Normalization of mid-term RE target between good practice and no policy curves. 100: the mid-term RE target level (in terms of %-share in total generation) equals the country-specific good practice scenario curve level 0: the mid-term RE target level (in terms of %-share in total generation) equals the country-specific no-policy scenario curve level	(IEA, 2018a; NewClimate Institute, Germanwatch and Allianz SE, 2018b; REN21, 2018)
Policies to level the playing field: Shift away from coal		[0,50,100] 100: A coal and/or oil phase-out date is agreed and fixed 50: No coal and/or oil phase out plan agreed yet but country has been vocal about its commitment to phase out (e.g. in international coalitions such as powering-past coal alliance) 0: Continued emphasis on coal/oil-based generation	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:1.3

Indicator M	Default weight w	Scoring	Data source
		'Agreed' – announced + part of a legal process (executive order, parliament decision etc.)	
Direct RE support policies	60%		
Direct support policies (feed-in schemes, RPS and tax measures)		[0,25,50,75,100] 100: Favourable support policies exist for ALL 4 major renewables (= small and large scale solar, onshore and offshore wind) and are complemented by conducive financial support policies and measures to mitigate financial risks i.e. all **five** support conditions are in place. 75: Either favourable support policies exist for only 3 renewable energy technologies with complementary financial support policies Or support policies exist for all 4 renewables but without complementary financial support policies and measures to mitigate financial risks i.e. only 4 of the 5 policy support conditions are met 50: Only an initial policy support exists (i.e. support policies cover less than 3 technologies and/or policy support is technology neutral) but **with** complementary conducive financial support policies 25: Only an initial policy support exists (i.e. support policies cover less than 3 technologies and/or policy support is technology neutral) but **without** complementary conducive financial support policies 0: No support for renewables / support announced but not yet implemented / Support schemes in place do not necessarily provide sufficient incentives to level the playing field for renewables against fossil fuel-fired technologies (e.g. only tax breaks and accelerated depreciation without other policies) To check 'favorability', check if RPS/RPO/Auctions/FiTs/FIPs are present for the following technologies: large and small PV and on-and off-shore wind (exception: include technologies that are critical in specific country contexts e.g. geothermal in Indonesia). For conducive finance policies, we looked for examples of **five** type of policies: 1) priority sector lending,2) differentiated interest rates,3) dedicated funding mechanisms and/or 4) green bonds issuance guidelines in the country. Other measures to mitigate financial risks in a developer's remuneration profile, we additionally look for 5) presence of additional guarantees etc. are also considered on case to case basis. Additionally, the assessment of this indicator allows for an in-depth assessment of a country's direct support policies (i.e. Tenders and Feed in tariffs) based on the actual capacities of each of the VRE technologies' allocated per support policy with respect to the current VRE capacity in a country. This approach is described in detailed in section 3.5.	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:2.1
Reliability of RE policies		[0 to 100]	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:1.4

Indicator M	Default weight w	Scoring	Data source
		Fluctuation of support measured by standard deviation of Climate Change Policy Index (CCPI) Energy Scores 2012-2018 on a 0 to 100 scale multiplied with CCPI Energy Scores 2012-2018 Reliability of support to renewables evaluates both historic support fluctuations and expected changes to the renewable policy framework ('party consensus'). The indicator is used to help assess whether investors can have certainty that countries follow through on their renewable energy policies and based on a survey distributed to in-country experts. The CCPI Energy scores are based on expert judgment on party consensus regarding ambitious renewable energy policies (also on a 0 to 100 scale)	
Ensuring realization		[0,50,75,100] 100: Ensuring the projects are really implemented For auctions all three criteria are fulfilled :(1) Pre-defined realisation periods in policy schedules exist, (2) pre-qualification requirements can help identify "serious" bids and eliminate projects with low realisation probability (3) effective penalties for non-realisation. For FITs always given (generally do not have a similar need) 75: For auctions: two of the three above 50: For auctions: one of the three above 0: None of the above	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:2.2
Energy efficiency policy	20%	[Relative scoring between 0 to 100] Composite indicator scores from the 2018 ACEEE International Energy Efficiency Scorecard is used. 0: No national efforts on energy efficiency or energy efficiency policies in the buildings, industry and transport sectors exist 100: Maximum number of energy efficiency policies in the buildings, industry, and transport sectors are present in a country. Additionally, national efforts on energy efficiency exist. National efforts consider the following policies (and metrics): energy productivity, change in energy intensity, efficiency in thermal power plants, mandatory saving goas, tax credits and loan programmes, energy efficiency spending, and energy efficiency research and development spending. Policies (and metrics) in the buildings sector include: policies on energy use in residential and commercial buildings, commercial and residential building codes, building labelling, appliance and equipment standards and labelling. Policies (and metrics) in the industry sector include: energy intensity policies, policies on industrial power generation, voluntary energy performance agreements, mandate for energy plant managers, mandatory energy audits.	(Castro-Alvarez *et al.*, 2018)

Indicator M	**Default weight** w	**Scoring**	**Data source**
		Policies (and metrics) in the transport sector include: passenger vehicle fuel economy, fuel economy standards, energy intensity of freight transport, use of public transit, and investment in rail transit.	
Barrier factors	Max. 20% reduction of the aggregate score of below sub-indicators		
Fossil fuel production		[Relative scoring between 0 to 100] 100: The country produced more coal and gas than it consumed domestically in 2016. 1-99: Linearly scaled between 100 and 0 depending on the share 0: The country produced no coal or gas domestically in 2016.	(IEA, 2018a)
Administrative procedures		[0,50,100] 0: Streamlined procedures for permitting renewable energy projects speed uptake 50: Standard administrative procedures or no information 100: Bureaucratic and in-transparent procedures are inhibitory.	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category:2.2[4]
Zoning/siting		[0,50,100] 0: The country has carried out strategic planning or produced zoning guidance to inform the commercial development of both solar AND wind resources. 50: The country has carried out strategic planning or produced zoning guidance to inform the commercial development of either solar OR wind resources. 100: The country has carried out NO strategic planning or produced zoning guidance to inform the commercial development of solar and wind resources.	(Worldbank, 2017)
(Optional) General investment conditions		[Relative scoring between 0 to 100] 0: Good general investment conditions based on macro economic and governance indicators. 100: Bad general investment conditions based on macro economic and governance indicators.	(NewClimate Institute, Germanwatch and Allianz SE, 2018b). Category 5[5]

[4] The score was adapted from Allianz Energy and Climate Monitor 2018 category 2.2 (NewClimate Institute, Germanwatch and Allianz SE, 2018b)
[5] The score was adapted from Allianz Energy and Climate Monitor 2018 category 5 (NewClimate Institute, Germanwatch and Allianz SE, 2018b)

Indicator M	Default weight w	Scoring	Data source
		The general investment conditions indicator refers to the score of a country on a range of factors determining overall investment conditions, which influence an investor's perception of risks and returns when investing in a country. General investment conditions consider the following determinants: 1. Non-financial determinants: This set of indicators reflects the safety of investments in a country. A high score reflects the ease of investing in a country. 2. Financial determinants: Financial determinants facilitate investor confidence towards return on investment in a country. 3. Macroeconomic fundamentals: These variables provide some resilience to a country from external shocks; especially so in emerging markets.	

3 Tool setup

The Variable Renewable Energy (VRE) policy modelling tool is a spreadsheet-based tool. The current version of the tool consists of roughly four different sections with one or more sheets each. These sections are:

1. Introduction & Instructions
2. Dashboard
3. Results
4. Default Country Results, and
5. (In-depth) calculations.

Each of these sections is explained below.

3.1 Introduction & Instructions

The introduction sheet provides an overview of the tool, description of sheet content and navigation to other sheets. The instructions sheet provides a detailed explanation on how to use the dashboard and the data inputs required in the model.

3.2 Dashboard

The dashboard is an interactive sheet, where data for country analysis needs to be entered and results are displayed dynamically based on that data. The tool's dynamic set up allows users to immediately see the results of a projection, when changing any of the input variables (this includes country specific data, weights and reference values). See Figure 4 for a partial overview of the dashboard.

The dashboard comprises of five panels:

A) **Results:** Graph of historical and projected share of VRE in total electricity projection. The graph is dynamically updated based on the input provided, it also automatically aligns to the top left corner of the Dashboard when clicking within the sheet. See Figure 5 for a detail of how graphical results are displayed in the dashboard.
B) **Instructions:** simple instructions to use the Dashboard and a button to navigate to full instructions. See Figure 6 for a detail look at the dashboard's panel B.
C) **Required input:** Selection of country. Option to use prefilled default values for default countries (G20 excl. EU) or to manually adjust input variables (see Figure 7 for details):

   C.1) Policies affecting the ceiling (see Figure 8 for details)

   C.2) Policies affecting the pace of growth (see Figure 9 for details)

   C.3) Barriers to the pace of growth (see Figure 10 for details)

   Additionally, Panels C.1 to C.3 contains the weights used for each of the input variables/indicators. Cells in yellow can be manually adjusted, and default values for weight can be restored by clicking the button next to the heading.

D) **Optional input:** Financial and non- financial barrier. Option to include financial and non-financial determinants as a barrier to VRE development in the selected country. The tool allows for the option of using prefilled default values for this barrier based on the results of Allianz Energy and Climate Monitor's category 5:General Investment Conditions (NewClimate Institute, Germanwatch and Allianz SE, 2018b). The general investment conditions indicator refers to the score of a country on a range of factors determining overall investment conditions, which influence an investor's perception of risks and returns when investing in a country. See Figure 11 for an overview of this dashboard's panel.

E) Optional input: Reference values. Option to manually edit the reference values used to estimate good practice and no policy curves. Option to restore default values by clicking the button at the heading. See Figure 12 for an overview of this dashboard's panel.

Figure 4 below shows a partial overview of the dashboard, where the panels mentioned above (excl. Panel D) can be observed. Each of the panels are shown in detail in the next sections.

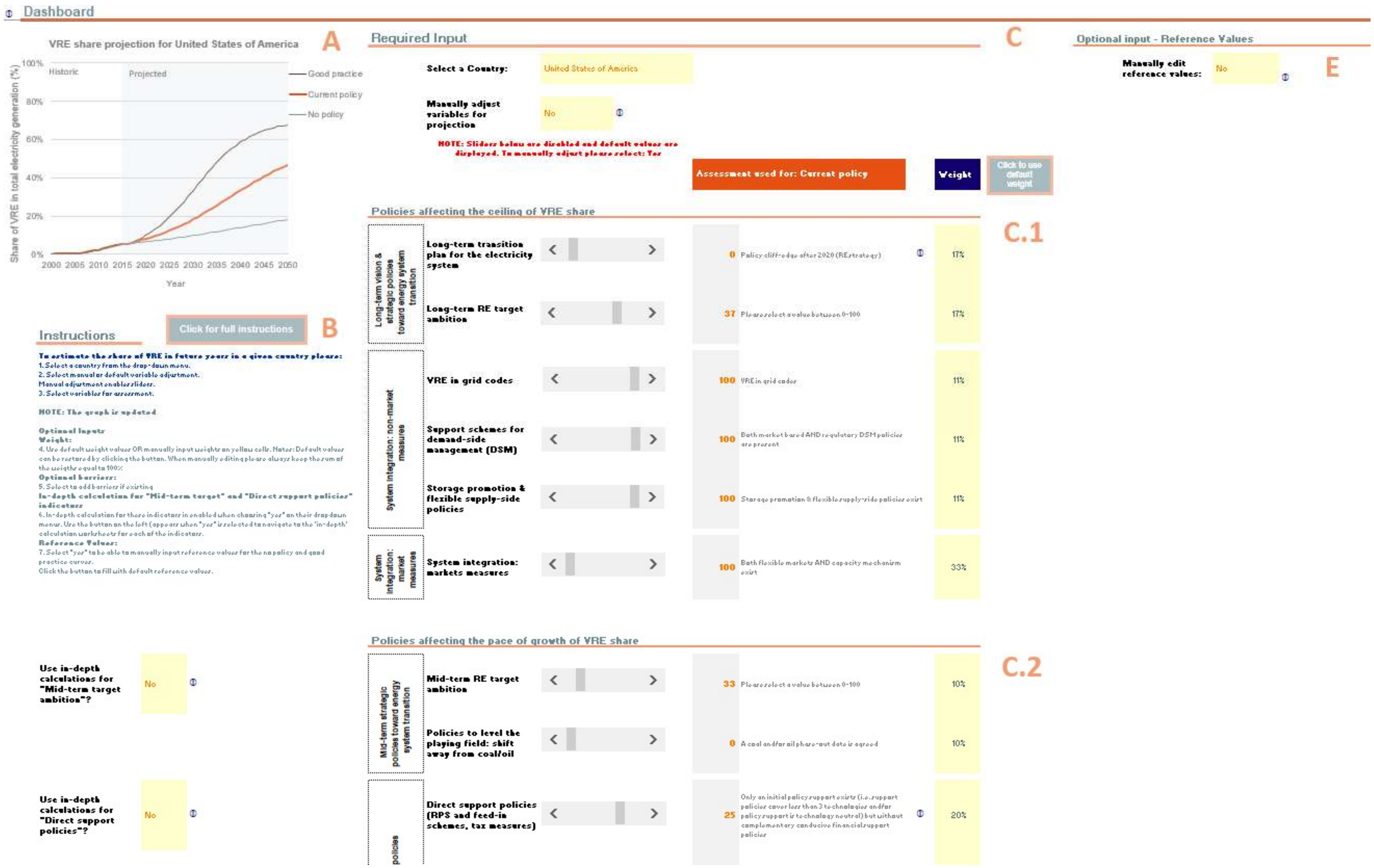

Figure 4. Dashboard VRE policy impact forecast tool divided in different panels

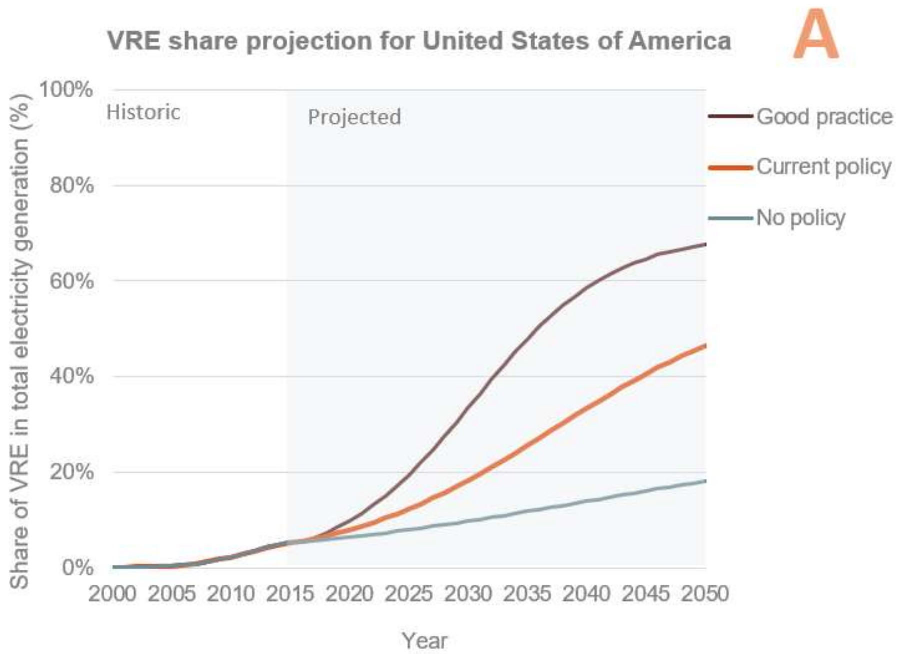

Figure 5. Dashboard Panel A, graphic results of VRE policy assessment. Historical values are calculated based on (IEA, 2018a)

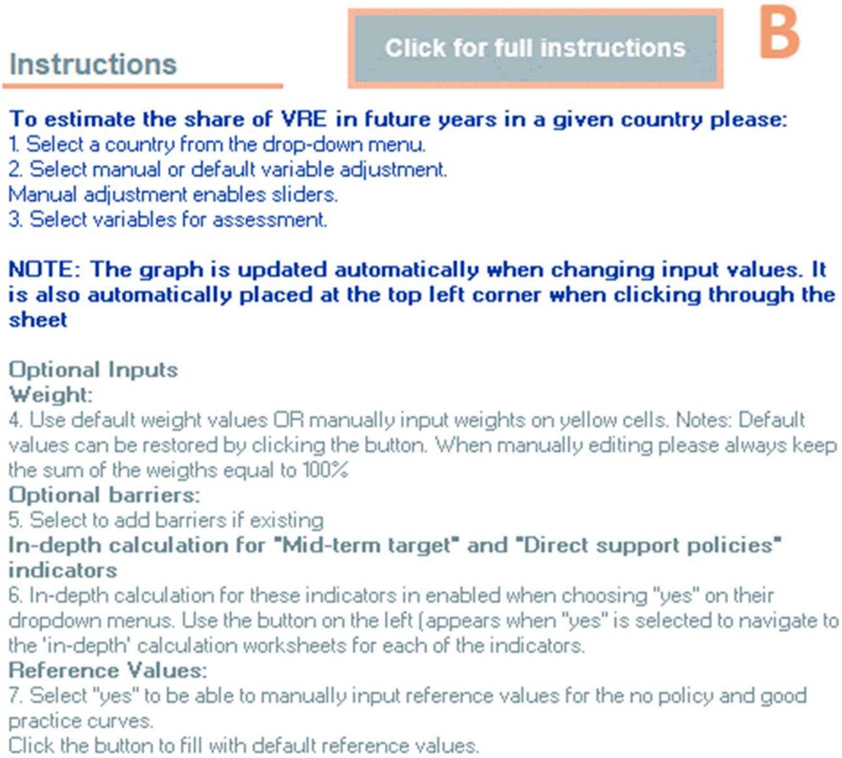

Figure 6. Dashboard panel B. Short instructions.

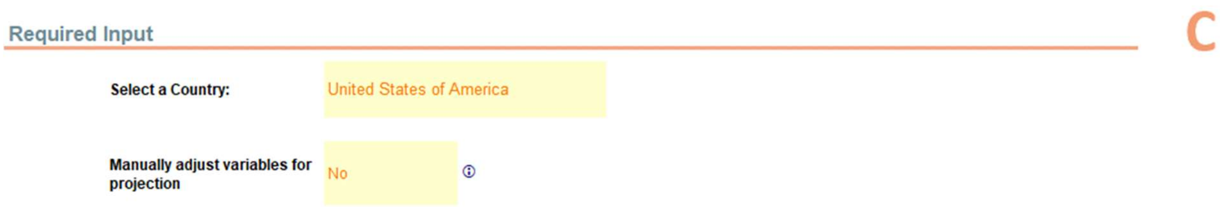

Figure 7. Dashboard panel C. Required input: selection of country and selection to use default data (Note: default data only available for a number of countries)

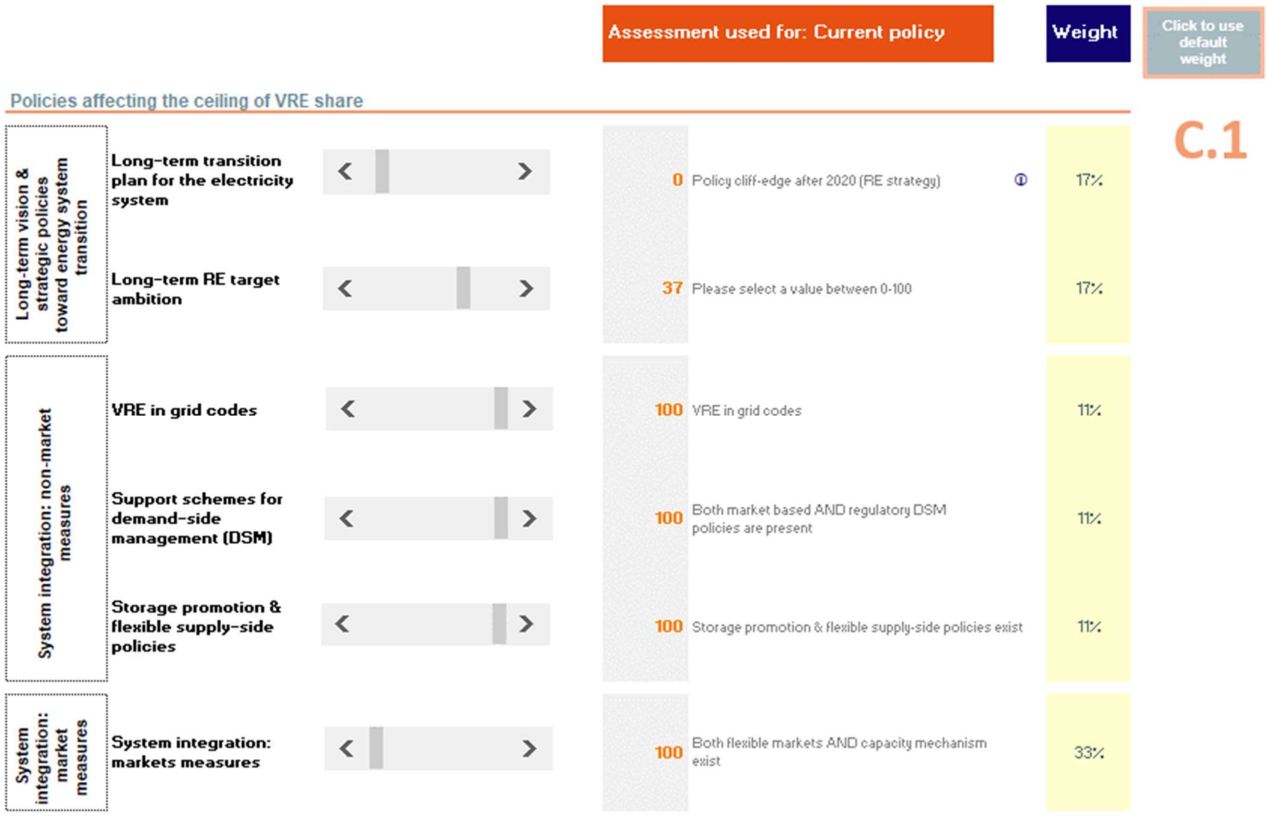

Figure 8. Dashboard panel C.1 Required input: assessment and weight for policies affecting the ceiling

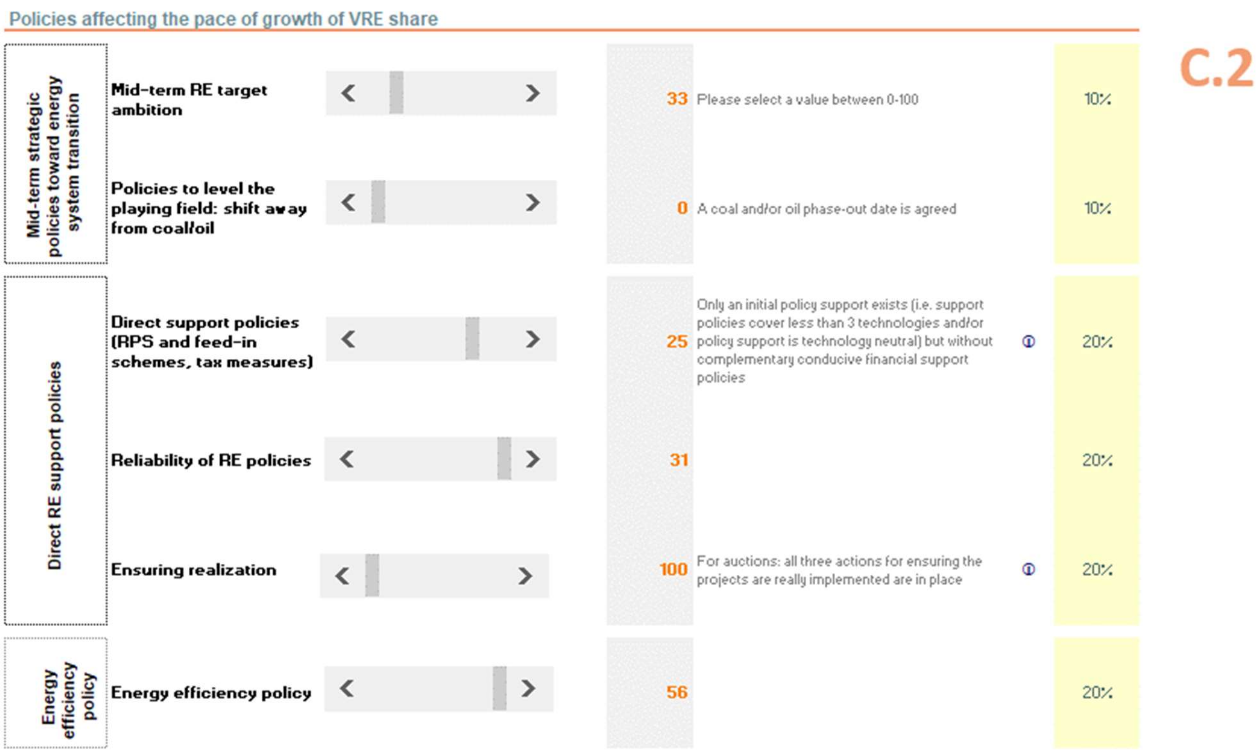

Figure 9. Dashboard panel C.2. Required input: assessment and weight for policies affecting the pace of growth.

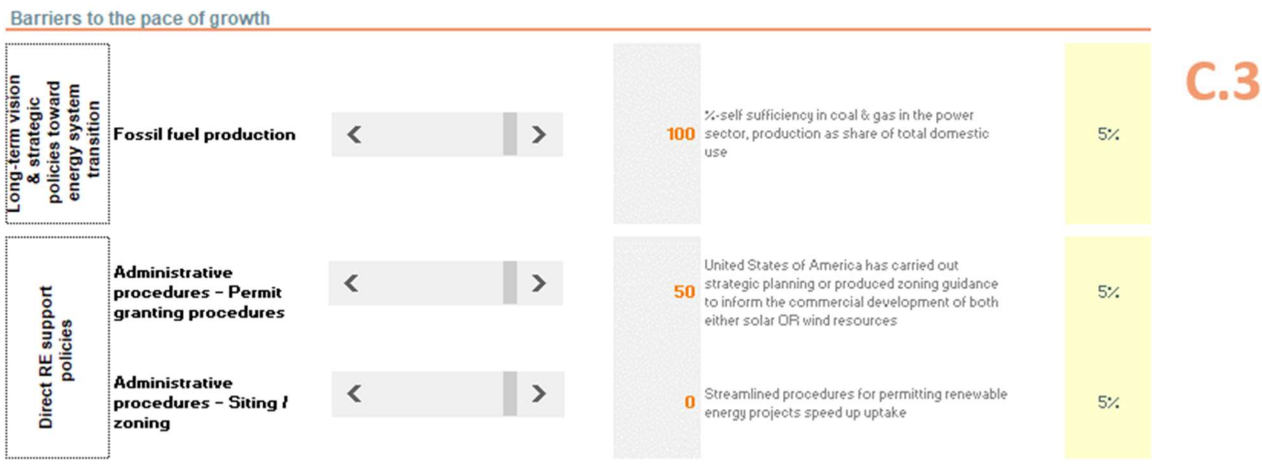

Figure 10. Dashboard panel C.3. Required input: assessment and weight for barriers to the pace of growth.

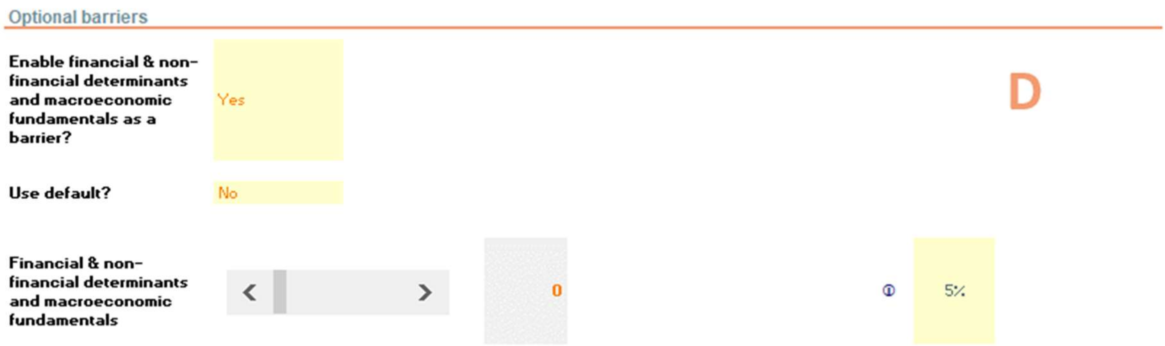

Figure 11. Dashboard panel D. Optional input: Financial & non-financial barriers.

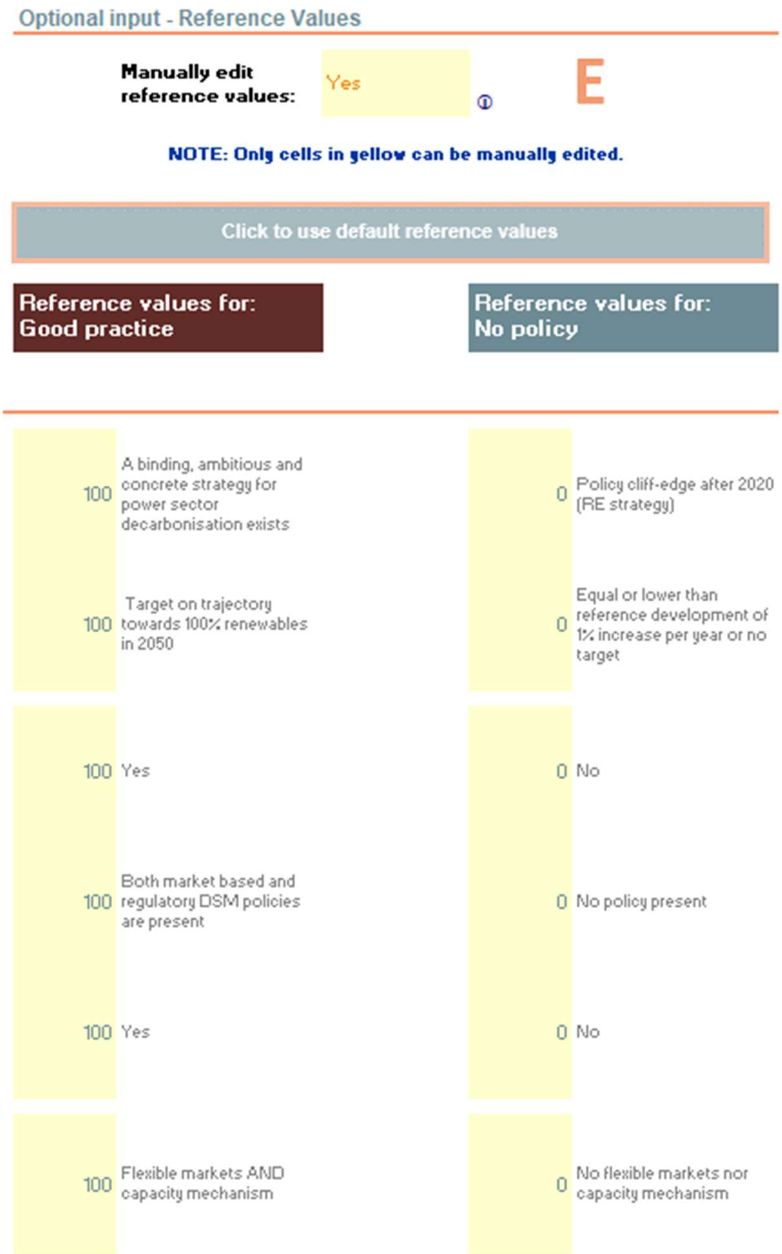

Figure 12. Dashboard panel E. Optional input: manually edit reference values for good practice and no policy curves.

3.3 Results

This sheet provides a graph and a full time series of %VRE for the three curves: good practice, current policy and no policy. These values are updated automatically when changing any of the input values in the Dashboard.

3.4 Default Country Results

This sheet provides an overview of input variables and results on VRE generation share for G20 countries (excl. the European Union). In this sheet, available default data as well as results for default countries are available for comparison. The user can choose a country at the top left and immediately see the input data and results for that country, which are automatically highlighted in the available graphs.

Additional to this tools' VRE share forecast, we compare %VRE to other projections from available literature sources. Some of these sources include: IEA WEO CPS 2018 (IEA, 2018b), Climate Action Tracker Decarbonisation scenarios (CAT Decarb) (Climate Action Tracker, 2018), projections from CTI tools version 02.04.2018 based on Monteith et al. (2016), PRIMES REF2016 scenario projections (for EU countries) (E3M Lab and National Technical University of Athens, 2016), IRENA REmap and reference case scenarios (IRENA, 2015), IEA Renewables 2017 (IEA, 2017), and countries mid-term targets (NewClimate Institute, Germanwatch and Allianz SE, 2018b). For more details on default countries input data and results see Section 4 (Country examples) below. °

3.5 In-depth calculations

The tool offers the option of adding in-depth calculations for the "Direct support policies" indicator. While the default data for this indicator is based on (NewClimate Institute, Germanwatch and Allianz SE, 2018b) category 2.1 and takes into account the existence of:

- renewable portfolio standards (RPS)
- renewable purchase obligations (RPO)
- Auctions
- Feed in tariffs (FiTs)
- FIPs

for the large and small PV and on-and off-shore wind in all G20 countries (excl. EU), we offer the option to estimate this indicator based on the quantification of capacity awarded trough tenders and FiTs with cap for the same technologies. The problem of the indicator presented by (NewClimate Institute, Germanwatch and Allianz SE, 2018b) is that it gives very little insights/ assess only to a limited extend on the ambition on the policy: this is only included indirectly as the inclusion of more technologies also often coincides with a higher level of development of renewables. However, this can differ tremendously as historical examples have shown. The in-depth methodology allows the user to overwrite this with a direct comparison of the expected installed capacity from the policy with a potential best practice policy development.

To enable this please select "yes" on the button to the left of the indicator in the dashboard and click the navigation button to the InDepth_DirectSupport" sheet (see Figure 13). Once in the "InDepth_DirectSupport" sheet please provide required input in yellow cells.

Figure 13. Option to add in-depth calculations for indicator: “Direct support policies”.

4 Country examples

To test the model used in the VRE policy impact forecast tool, data for G20 countries (excl. the European Union) was collected. The data was used to estimate projections on share of VRE in total electricity generation for a total of 19 countries. An overview of the indicators collected for the ceiling factor, pace of growth factor and barrier to the pace of growth can be seen in Figure 16, Figure 14, and Figure 15, respectively.

The projections of future VRE share, were compared to other projections available in literature for selected countries. The results are shown below in Figure 18 and Figure 19

4.1 Input: Drivers and Barriers

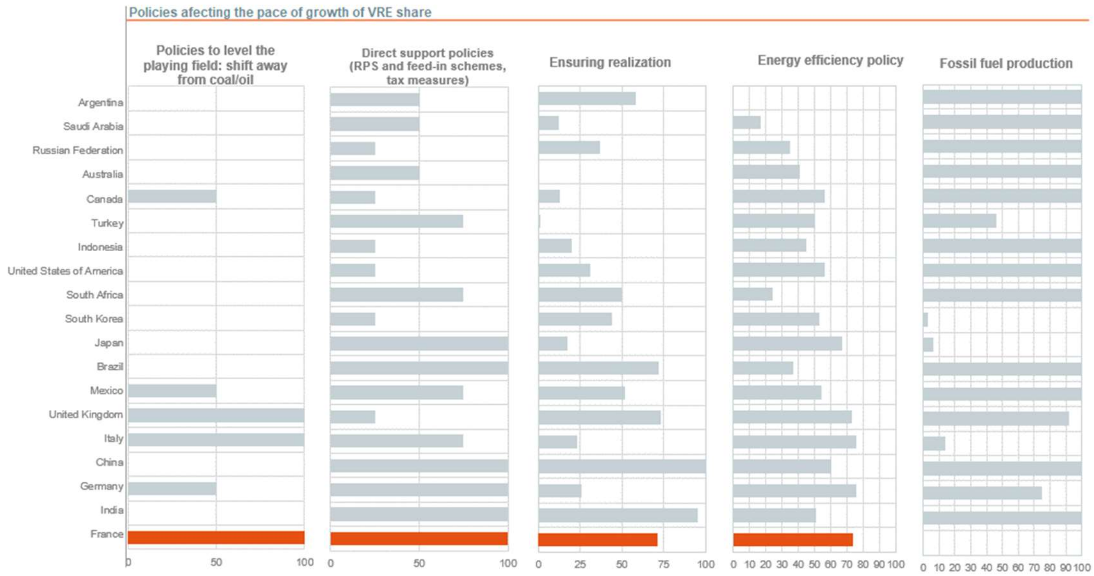

Figure 14. Overview of policies affecting the pace of growth for default countries.

Figure 15. Overview of barriers to the pace of growth for default countries.

Figure 16. Overview of input drivers affecting the ceiling factor for default countries

4.2 Intermediate results for default countries

Figure 17. Results for the incentive factor, ceiling factor, overall growth factor (including pace of growth factor and barrier) and (optional) barrier factor

4.3 Results and data validation for selected countries

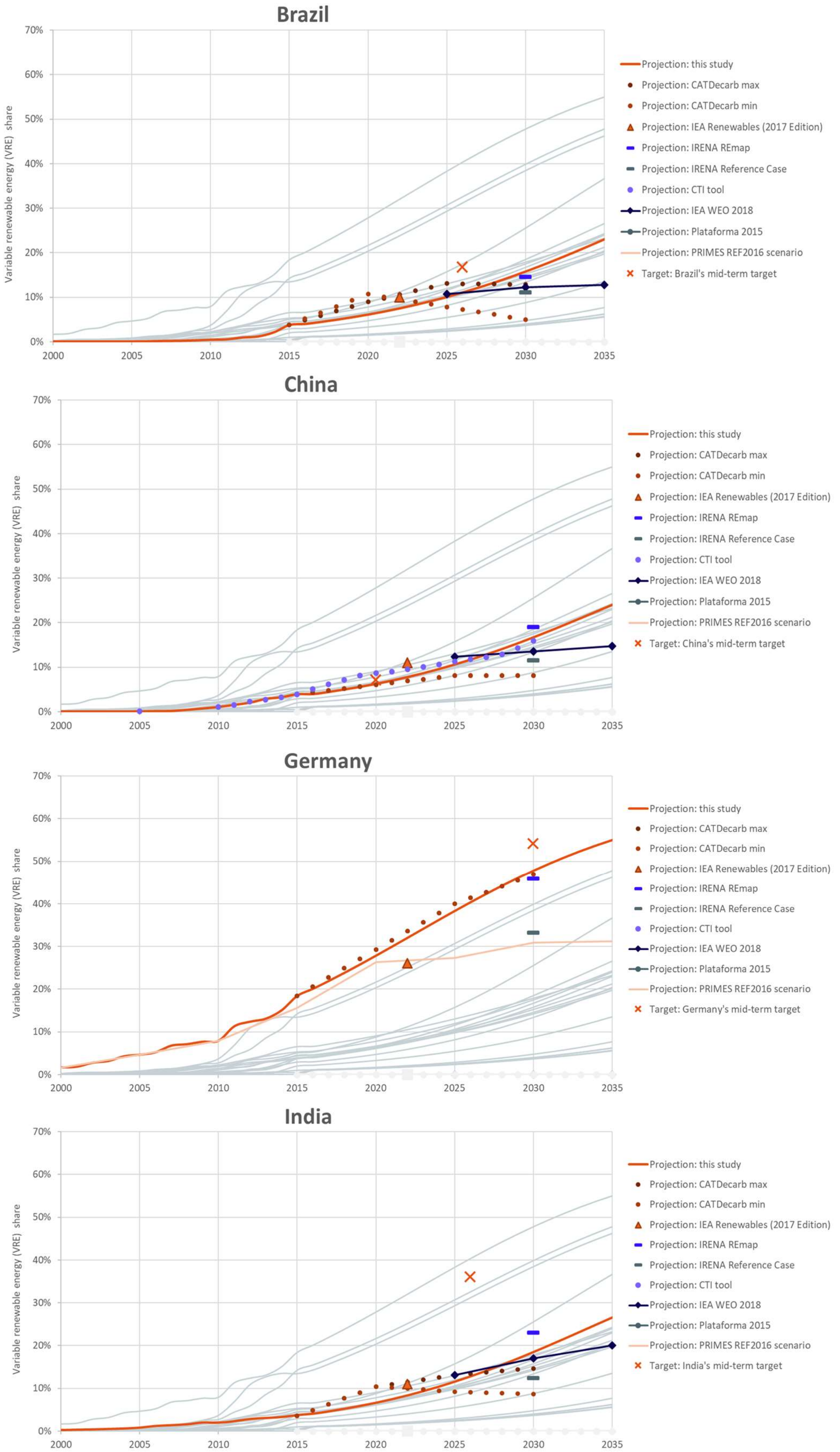

Figure 18. Results for selected default countries (part 1)

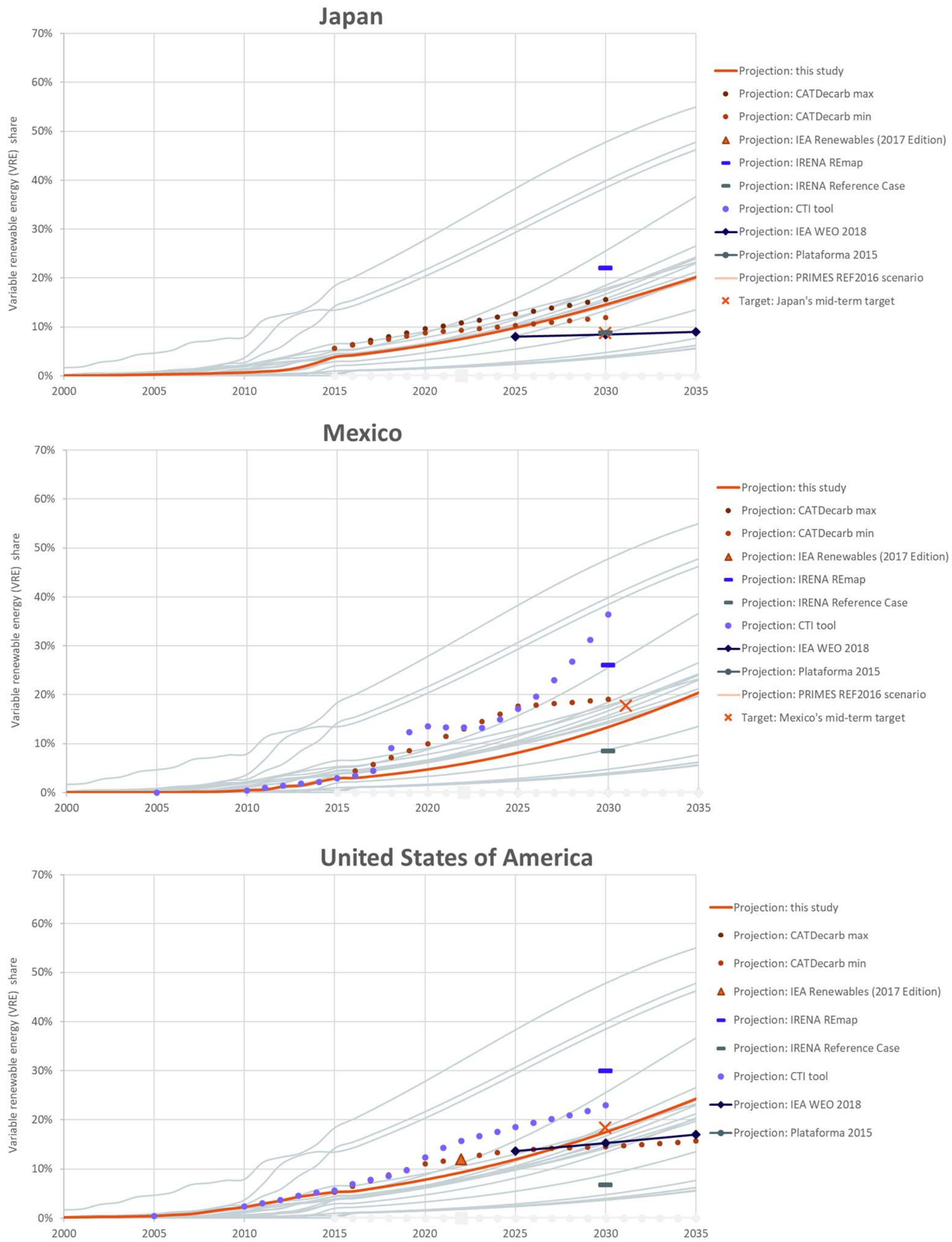

Figure 19. Results for selected default countries (part 2)

5 Limitations

Technology diffusion is a complex process comprising of many variables. Thus, any model—a simplification that aims to understand some of the relation between variables—cannot fully reproduce, let alone forecast future developments. Some of the limitations of our variable renewable energy policy impact forecast tool are:

- Given that our tool starts VRE share projection based on current historical in 2015 by applying growth rate, countries with current zero/almost zero VRE remain at zero VRE share in the future. We have thus applied a threshold of 1% to countries with current historical VRE share of less than 1%. For these countries, the "current policy" curve starts at 1%.
- The effect of technology advancements and other learning effects, which may lead late commers to have a much steeper curve than our good practice curve, is not accounted for in the tool. This is the case because our tool is based on the main premise that the estimated current policy projection lies between a good practice and a no policy curves. This means that the current policy curve's maximum pace of growth being limited by the speed of growth of the good practice curve.

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Annex I: Rationale for the selection of policy indicators

A1.1 Policy indicators affecting both the long-term potential and the speed of variable renewable electricity deployment

A1.1.1 Long-term vision and strategic policies toward energy system transition

An analysis of OECD countries (Polzin *et al.*, 2015) confirmed earlier conceptual and empirical works (De Jager *et al.*, 2008, 2011; Lüthi and Wüstenhagen, 2012) that a clear commitment and strategic energy planning for the long term is conducive to investments in renewable energy. A long-term strategic planning would ideally also consider future major reductions in energy consumption as well as the transition of the electricity infrastructure, both of which are essential to realise decarbonisation of electricity.

As this tool aims to assess the policy impact on solar and wind power deployment, we considered two sub-indicators: (i) long-term transition plan for the energy system and (ii) ambition level of long-term renewable electricity targets. The first sub-indicator assesses whether the entire economy of a country has a clear and well-designed transition toward decarbonisation, while the second sub-indicator considers specifically the long-term ambition for renewable electricity deployment.

A1.1.2 Policies and market measures to support system integration of variable renewable energy technologies

An energy system needs flexibility to allow for large amount of variable renewable electricity generation without disrupting demand and supply balance. Lund et al. (Lund *et al.*, 2015) categorises system flexibility measures into following categories:

1) demand side management (e.g. peak shaving, valley filling, load shifting, and conservation),
2) energy storage (e.g. pumped hydro, batteries, and hydrogen)
3) supply-side flexibility (e.g. power plant response, curtailment, and gas-fired combined cycle power plants)
4) advanced technologies (e.g. power-to-hydrogen (P2H) vehicle-to-grid (V2G) technologies),
5) infrastructure (grid infrastructure and geographical smoothing of spatial power fluctuation),
6) grid ancillary services (e.g. addressing system stability issues for different time scales, from milliseconds to several months, by applying all of measures 1)–5))
7) electricity markets (e.g. capacity market mechanisms, market-based measures for energy storage and demand side management)

IRENA (2018b) also confirms that many of these measures should be considered for countries and regions with relatively high shares of VRE in total electricity generation (roughly above 10%, with exceptions). Not a lot of countries have reached such high shares of VRE, especially if one consider that those that have are often part of a larger interconnected system.

Therefore, this tool concentrates on early stage and preparational measures. The following four binary sub-indicators measuring policy presence to assess countries' efforts to enhance system flexibility are assessed:

- VRE in grid codes (roughly corresponding to (6) above),
- support schemes for demand-side management (DSM: corresponding to (1) above),
- storage promotion and flexible supply-side policies (corresponding to (2) and (3) above), and

- market measures including flexible markets and capacity-based mechanisms (corresponding to (7) above).

Infrastructure-related issues are partially covered by the assessment of long-term energy system transition plan (section 0) and direct support policy measures presented in section 0.

We did not assess the aforementioned policies against certain quantitative benchmarks because optimal flexibility depends on how all the measure described above are combined. For example, Kondziella and Bruckner (2016) concluded based on an extensive literature review that there is no evidence that a certain level of energy storage capacity would be technically required for system stability because the curtailment of VRE and "flexible power plants" such as gas-fired ones can also be sufficient to balance the system. However, this is a very dynamic field and new challenges emerge as countries increase the share of VRE. Hence this section renders a great potential for being updated in the future.

A1.2 Policy indicators that affect the speed of variable renewable electricity development

A1.2.1 Mid-term strategic policies toward energy system transition

Mid-term renewable electricity targets

Setting short- to mid-term targets is an important step towards large scale renewable energy deployment; over 150 countries have set renewable electricity-related targets by the end of 2017 (REN21, 2018). Setting short- to mid-term targets for renewable electricity generation or capacity provides certainty for investors.

We considered this policy sub-indicator to affect speed of growth in renewable electricity deployment. An unambitious target is assumed to slow down the pace of growth but not to inhibit reaching the long-term potential available in the country.

Shift away from coal

Transition to a decarbonised power sector also requires policies to reduce reliance on fossil fuels (Carley *et al.*, 2017). Expenditures and investments on fossil fuels (as well as nuclear) and the related infrastructure are shown to be inhibitors against renewable energy deployment (Romano and Scandurra, 2016; Carley *et al.*, 2017).

In our analysis, we considered to be a good practice when a country has a clear roadmap towards the phase-out of coal-fired power plants (including a target year), supported by measures to limit new coal-fired power plant constructions and accelerate retirement of existing plants.

Our analysis did not consider policies to reduce power generation from other fossil fuels. Oil-fired power generation is less than 5% of global total generation and the gas-fired power generation is considered to be an important option to maintain system flexibility on the supply side in the short to mid-term (see section **Error! Reference source not found.**).

A1.2.2 Direct RE support policies

See the 2018 Allianz Climate and Energy Monitor documentation for details (NewClimate Institute, Germanwatch and Allianz SE, 2018b; p.15).

A1.2.3 Energy efficiency and demand reduction policies

As described in A1.1.1, absolute reduction of energy consumption facilitates achieving full decarbonisation of the electricity system; the smaller the electricity demand is, the less renewable electricity has to be generated to achieve full decarbonisation. Energy demand reduction is essential for increasing the share of renewables in the energy system. We refer to the 2018 International Energy Efficiency Scorecard developed by the American Council for an Energy-Efficient Economy (Castro-Alvarez *et al.*, 2018).

A.1.2.4 Barrier factors

We identified a set of barrier factors that would hinder renewable electricity deployment.

Fossil fuel production

A number of studies have statistically shown a negative correlation between fossil fuel production. A panel data analysis on 108 developing countries between 1980 and 2010 found that high fossil fuel production delayed non-hydro RE diffusion (Pfeiffer and Mulder, 2013). Another panel data analysis on the EU member states between 1995 and 2014 (Papiez, Smiech and Frodyma, 2018) found that the countries with the lowest shares of RE were the ones with relatively high energy self-sufficiency, and that the countries without their own fossil fuel sources are the ones which develop RE to the greatest extent. Conceptually this can be directly linked to matters of security of supply: In countries where the fossil fuel production is low, renewables help decrease the import dependence more significantly than in countries where fossil fuel production is high.

Administrative procedures

See the 2018 Allianz Climate and Energy Monitor documentation for details (NewClimate Institute, Germanwatch and Allianz SE, 2018b; p.17).

Zoning and siting

Zoning, i.e. identification of suitable areas for deployment of VRE, not only helps investors making necessary decisions but also helps identifying locations where there is demand for electricity or planning VRE deployment in locations where the grid network is lacking (IRENA, 2018b).

General investment conditions (optional)

A panel data analysis on the EU member states for years 2004–2011 (Cadoret and Padovano, 2016) found that a standard measures of governance quality, i.e. Control of Corruption Index from the World Governance Indicators, positively affects RE deployment.

Hu et al. (Hu, Harmsen, Crijns-Graus and Worrell, 2018) argue that a comprehensive policy framework to support VRE investments should be considered in a broader context that also includes monetary and fiscal policies, based on the historical observations that access to bank lending has been affected by side-effects of monetary policy.

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