International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: repository@iiasa.ac.at
Web: www.iiasa.ac.at

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Connecting the Sustainable Development Goals by their energy inter-linkages

David L. McCollum* (mccollum@iiasa.ac.at); Luis Gomez Echeverri (gomez@iiasa.ac.at); Sebastian Busch (busch@iiasa.ac.at); Shonali Pachauri (pachauri@iiasa.ac.at); Simon Parkinson (parkinso@iiasa.ac.at); Joeri Rogelj (rogelj@iiasa.ac.at); Volker Krey (krey@iiasa.ac.at); Keywan Riahi (riahi@iiasa.ac.at); Måns Nilsson (mans.nilsson@sei-international.org); Anne-Sophie Stevance (anne-sophie.stevance@icsu.org)

Approved by

Pavel Kabat

Director General/CEO, IIASA

*Corresponding author.

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Contents

Abstract

The United Nations' Sustainable Development Goals provide guide-posts to society as it attempts to respond to an array of pressing challenges. One of these challenges is energy; thus, the SDGs have become paramount for energy policy-making. Yet, while governments throughout the world have already declared the SDGs to be "integrated and indivisible", there are still knowledge gaps around how the interactions between the energy SDG targets and those of the non-energy-focused SDGs might play out in different contexts. In this Perspective, we report on a systematic assessment of the relevant energy literature, which we conducted to better our understanding of key energy-related interactions between SDGs. Our analysis indicates, first, that positive interactions between the SDGs outweigh the negative ones, both in number and magnitude. Second, of relevance for the scientific community, in order to fill knowledge gaps in critical areas, there is an urgent need for inter-disciplinary research geared toward developing new data, scientific tools, and fresh perspectives. Third, of relevance for policy-making, wider efforts to promote policy coherence and integrated assessments are required to address potential policy spillovers across sectors, sustainability domains, and geographic and temporal boundaries. 'Doing energy right' is fundamental to the success of the SDGs, and energy scientists have a major role to play in offering guidance to the discourse.

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About the Authors

David McCollum is a Research Scholar with the Energy Program at IIASA.

Luis Gomez-Echeverri is a Senior Research Scholar with the Transition to New Technologies (TNT) Program at IIASA and a Senior Advisor to Sustainable Energy for All (SEforALL).

Sebastian Busch is a Research Scholar with the Transitions to New Technologies Program at IIASA.

Shonali Pachauri is a Senior Research Scholar with the Energy Program at IIASA.

Simon Parkinson is a Research Scholar with the Energy Program at IIASA.

Joeri Rogelj is a Research Scholar with the Energy Program at IIASA.

Volker Krey is the Deputy Energy Program Director at IIASA.

Keywan Riahi is the Energy Program Director at IIASA.

Måns Nilsson is the Research Director and Deputy Director at the Stockholm Environment Institute.

Anne-Sophie Stevance is Science Officer, International Council for Science (ICSU)

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Introduction

In September 2015, United Nations Member States adopted a comprehensive global development agenda: *Transforming our world: the 2030 Agenda for Sustainable Development*, more commonly known as the Sustainable Development Goals (UN, 2015). The SDGs, which can be viewed as a successor to the Millennium Development Goals (MDGs) before them, represent a major shift in the global policy landscape. For the first time, sustainable development, broadly defined and all-encompassing, has been enshrined in international – and, by extension, national – policy discussions. The 17 SDGs cover everything from energy and climate; to water, food and ecosystems; to health and poverty; to jobs and innovation; among a number of other objectives. (See Supplementary Discussion for the UN's original *2030 Agenda* text spelling out the details of all SDGs.) This represents a major step forward from the MDGs, which, in addition to not being universal in nature, were silent on a number of these dimensions, notably energy. Energy is dealt with primarily by Sustainable Development Goal #7 (SDG7), whose overarching aim is to "Ensure access to affordable, reliable, sustainable and modern energy for all". Underpinning this grand objective are three distinct, yet related, pillars ('Targets'):

- 7.1 || By 2030, ensure universal access to affordable, reliable and modern energy services
- 7.2 || By 2030, increase substantially the share of renewable energy in the global energy mix
- 7.3 || By 2030, double the global rate of improvement in energy efficiency

Governments throughout the world have already declared the 17 SDGs and their 169 targets to be "integrated and indivisible" (UN, 2015). Yet, the interactions between the energy and 'non-energy' SDGs are not fully understood. The scientific community has a critical role to play here in elucidating where the linkages are strong or weak, as well as what they depend on. One key question for decision makers is how the new SDG framing might – or should – affect energy policy and development strategies in individual (or groups of) countries. After all, the impacts of energy extraction, conversion, and consumption activities on other sectors (i.e., sustainability domains) are far-reaching – be those impacts *economic*, *social*, or *environmental* in nature. Here we assess the scientific literature exploring the impacts of the kinds of energy solutions enumerated by SDG7 (renewables, efficiency, energy for the poor) on a variety of other SDG objectives. Based on this review, we employ a simple scale for scoring the nature of the interactions identified. The study's aims are two-fold: firstly, to highlight for decisions makers how energy policy choices may affect other SDG objectives and especially those contexts in which implementation practices are pivotal in shaping those effects, and secondly, to provide energy researchers with the current 'lay of the land' regarding SDG interactions studies, pointing to critical knowledge gaps the scientific community will need to fill over the coming years.

Interactions between energy and non-energy SDGs and targets

Below we take each of the 16 non-energy SDGs in turn, summarizing the principal interactions between the underlying targets of these SDGs and those of SDG7 (Energy). To quantitatively represent the direction and nature of these interactions, we assign scores to all of them, making use of the seven-point scale and associated language presented in Table 1 (see Nilsson et al. (2016) for an elaboration). The interactions may be either positive ('indivisible', 'reinforcing' or 'enabling') or negative ('constraining', 'counteracting' or 'canceling'); or the respective SDG targets may be entirely 'consistent' with each other, incurring no significant positive or negative interactions whatsoever, or simply not interacting at all.

Table 1. Scale used to assess the nature of the interactions between SDG7 (Energy) and the 16 non-energy SDGs. The table was originally published in Nilsson et al. (2016); reproduced with permission.

Interaction	Name	Explanation
+3	Indivisible	Inextricably linked to the achievement of another goal.
+2	Reinforcing	Aids the achievement of another goal.
+1	Enabling	Creates conditions that further another goal.
0	Consistent	No significant positive or negative interactions.
–1	Constraining	Limits options on another goal.
–2	Counteracting	Clashes with another goal.
–3	Cancelling	Makes it impossible to reach another goal.

Figure 1 lays out the result of our scoring exercise graphically, while Table 2 provides explanations for how we objectively arrived at our score determinations based on an assessment of the relevant literature. In total, we reviewed well over 150 studies exploring either the effects that energy solutions to the sustainability transition (renewables, efficiency, energy for the poor) may have on the 16 other SDG objectives or the effects that actions and policies in these other domains may have on the energy SDG targets themselves. (To be sure, more emphasis is placed on studies exploring the former relationship.) This inherently comprises a diverse array of literature from a variety of scientific disciplines. In order to keep the analysis tractable, we concentrated our attention on representative reference studies. Some of these take a national or sub-national focus, while others are more international. Most studies are forward-looking, though a number of them are case-studies that take a historical perspective. In several instances, literature reviews assessing an entire class of literature are relied upon.

After categorizing the many studies by SDG dimension, we evaluated the robustness of the evidence base in each area as well as the degree of agreement of that evidence. From this, we derived interactions scores at the target level and a measure of our confidence in the scores assigned. We followed a systematic approach in arriving at these evaluations, observing guidelines on the consistent treatment of uncertainties provided by the Intergovernmental Panel on Climate Change for its Fifth Assessment cycle (Mastrandrea et al., 2011). Table 2 presents the sum result of our efforts. Single interactions scores for clusters of SDG targets are generally the norm; though, in some cases ranges are given. The latter can be more fitting either when a given effect depends strongly on context (e.g., jurisdictional unit where policy is implemented, the exact instruments utilized) or when the prevailing science tends not to agree regarding the nature of the particular interaction (i.e., when there is uncertainty).

A key insight that emerges from our analysis is that, as gleaned most easily from Figure 1, positive interactions between SDG7 (Energy) and the other SDGs clearly outweigh the negative ones, both in number and magnitude. (Note that the figure shows only one score per SDG. In instances where multiple interactions are present at the underlying target level, the individual score with the greatest magnitude takes precedence.) In other words, efforts to ensure access to modern energy forms for the world's poorest and to deploy renewables rapidly and accelerate the pace of energy efficiency improvements in all countries should, more often than not, be to the benefit of the broader sustainable development agenda – vis-à-vis a world in which vast inequalities in energy access remain and where energy supply, conversion and demand activities are inefficient and fossil-dependent. There are instances, however, where dis-benefits, or trade-offs, could emerge.

To take an example, substituting coal and natural gas in electricity generation with solar, wind and most other renewables (though perhaps not biomass), and subsequently using that electricity to power end-use processes in the transport, buildings, and industrial sectors will help to improve the air quality of cities throughout the world (SDG3). Cleaner air, in turn, means healthier populations that can more productively contribute to the economy. The literature is robust in this area, and scientific agreement is high regarding the positive impacts. We therefore assign a 'very high' level of confidence to the nature of this interaction and give it a score of [+2] ('indivisible') (see Table 2). Taking another example, if an expansion of renewables leads to large-scale bioenergy production globally, then there is a risk of competition with land for food production (SDG2) and water for multiples uses (SDG6). Increased food prices could potentially result in such a scenario, which would be to the detriment of the poor worldwide. The literature in this area is, at present, less robust, and while there is agreement about the potentially negative impacts (and the need for smart policies to minimize or avoid these impacts), more research appears to be needed. We therefore assign a ‘medium’ level of confidence to the nature of this interaction and give it a score of [0,-1] (‘consistent’ to ‘constraining’).

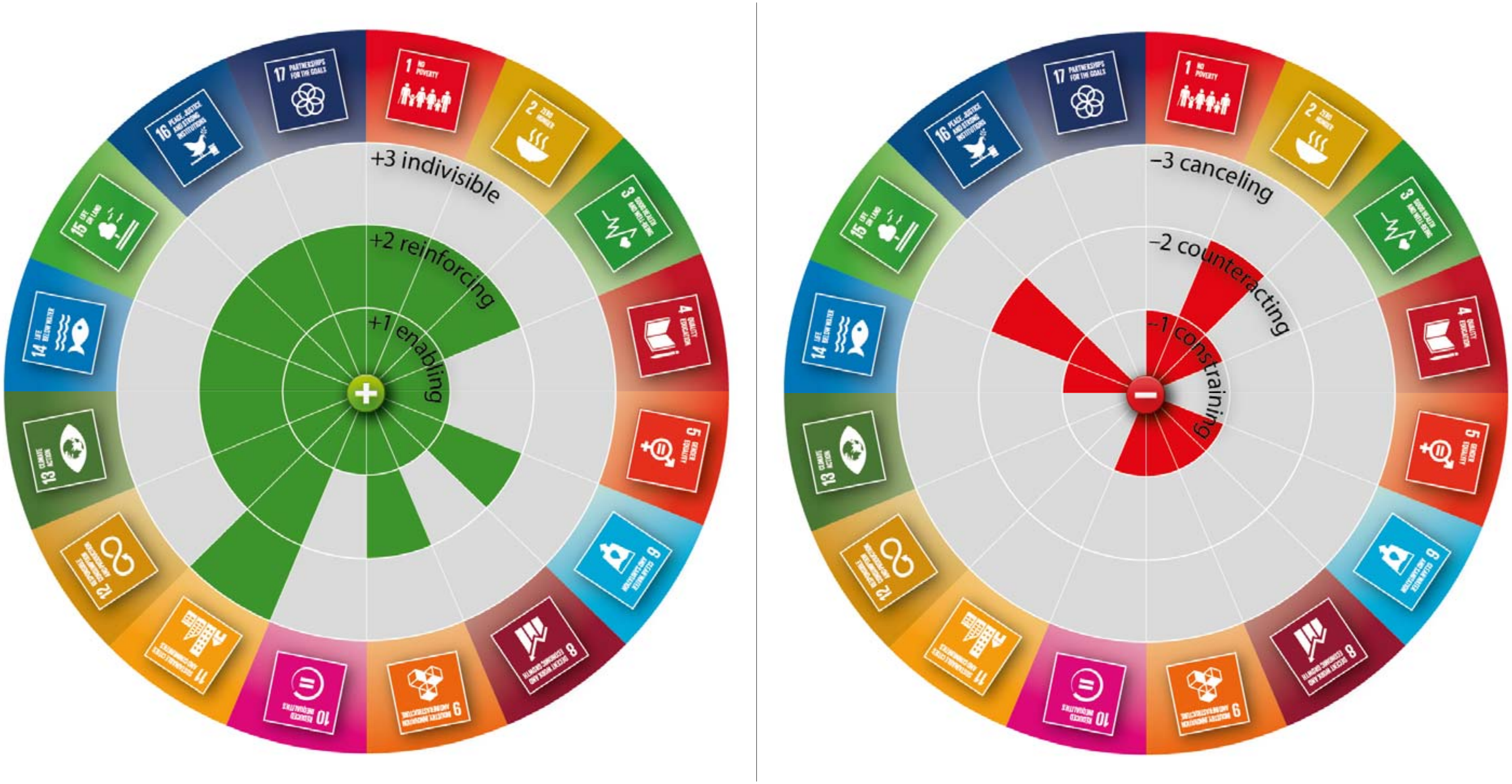

Figure 1. Nature of the interactions between SDG7 (Energy) and the 16 non-energy SDGs. The relationships may be either positive (left panel) or negative (right panel) to differing degrees. See Table 1 for definitions pertaining to each score from +3 (positive) to –3 (negative) in integer increments. The absence of a colored wedge indicates a score of 0 (‘consistent’). Note that, while not illustrated by this figure, some SDG linkages may involve more than simple two-way interactions (e.g., the energy-water-land ‘nexus’).

Table 2. Overview of the assessed literature and conclusions drawn on interactions between the targets of SDG7 (Energy) and those of the 16 non-energy SDGs. The table summarizes (i) literature we assessed in our review, (ii) key insights from the literature, (iii) robustness of the evidence base for a given SDG interaction, (iv) agreement within the literature for that interaction, and (v) our level of confidence in the scores assigned and the conclusions reached. As put forward in Mastrandrea et al. (2011), the following language can be used to describe the validity of a finding in the literature: the type, amount, quality, and consistency of evidence (summary terms: "limited," "medium," or "robust"), and the degree of agreement (summary terms: "low," "medium," or "high"); this then leads to an assessment of the level of confidence in a finding (summary terms: "very low," "low," "medium," "high," and "very high").

SDG	Target Category	Supporting Literature	Interactions Identified	Score	Evidence	Agreement	Confidence
1 NO POVERTY	Poverty and Development (1.1/1.2/1.3/1.4)	Pachauri et al. (2012); Casillas and Kammen (2010); Burlig and Preonas (2016); Bonan et al. (2014); Pueyo et al. (2013); Cook (2011); Rao et al. (2014); Kirubi et al. (2009)	Access to modern energy forms (electricity, clean cook-stoves, high-quality lighting) is fundamental to human development since the energy services made possible by them help alleviate chronic and persistent poverty. Strength of the impact varies in the literature.	[+2]	robust	high	*very high*
		Cameron et al. (2016); Jakob and Steckel (2014); Casillas and Kammen (2012); Hallegate et al. (2016); Fay et al. (2015); Hirth and Ueckerdt (2013)	The distributional costs of new energy policies (e.g., supporting renewables and energy efficiency) are dependent on instrument design. If costs fall disproportionately on the poor, then this could impair progress toward universal energy access and, by extension, counteract the fight to eliminate poverty.	[0,-1]	robust	high	*high*
	Exposure and Vulnerability (1.5)	Riahi et al. (2012); IPCC (2014); Hallegatte et al. (2016)	Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of the world's poor to climate-related extreme events, negative health impacts, and other environmental shocks.	[+2]	robust	high	*high*
2 ZERO HUNGER	Food Security and Agricultural Productivity (2.1/2.4)	Smith, P. et al. (2014); Tilman et al. (2009); Finco and Doppler (2010); Smith et al. (2013); Sola et al. (2016); Hasegawa et al. (2015); Lotze-Campen et al. (2014); Msangi et al. (2010); van Vuuren et al. (2009); Cabraal et al. (2005); Asaduzzaman et al. (2010)	Modern energy access is critical to enhance agricultural yields/productivity, decrease post-harvest losses, and mechanize agri-processing - all of which can aid food security. However, large-scale bioenergy and food production may compete for scarce land and other inputs (e.g., water, fertilizers), depending on how and where biomass supplies are grown and the indirect land use change impacts that result. If not implemented thoughtfully, this could lead to higher food prices globally, and thus reduced access to affordable food for the poor. Enhanced agricultural productivities can ameliorate the situation by allowing as much bioenergy to be produced on as little land as possible.	[0,-1]	medium	high	*medium*
	Farm Employment and Incomes (2.3)	Creutzig et al. (2013); Gohin (2008); de Moraes et al. (2010); Satolo and Bacchi (2013); van der Horst and Vermeylen (2011); Rud (2012); Balishter et al. (1991)	Large-scale bioenergy production could lead to the creation of agricultural jobs, as well higher farm wages and more diversified income streams for farmers. Modern energy access can make marginal lands more cultivable, thus potentially generating on-farm jobs and incomes; on the other hand, greater farm mechanization can also displace labor.	[+2]	robust	high	*high*
		van der Horst and Vermeylen (2011); Davis et al. (2013); Muys et al. (2014); Creutzig et al. (2013); Corbera and Pascual (2012)	Large-scale bioenergy production could alter the structure of global agricultural markets in a way that is, potentially, unfavorable to small-scale food producers. The distributional effects of bioenergy production are underexplored in the literature.	[0,-2]	medium	high	*medium*
3 GOOD HEALTH AND WELL-BEING	Disease and Mortality (3.1/3.2/3.3/3.4)	Aranda et al. (2014); Smith et al (2013); Lim et al. (2012); Lam et al. (2012)	Access to modern energy services can contribute to fewer injuries and diseases related to traditional solid fuel collection and burning, as well as utilization of kerosene lanterns.	[+2]	robust	high	*very high*
	Road Traffic Accidents (3.4/3.6)	Woodcock et al. (2009); Haines and Dora (2012); Shaw et al. (2014); Saunders et al. (2013); Creutzig et al. (2012)	'Active travel modes' (such as walking and cycling) represent strategies not only for boosting energy efficiency but also, potentially, for improving health and well-being (e.g., lowering rates of diabetes, obesity, heart disease, dementia, and some cancers). However, a risk associated with these measures is that they could increase rates of road traffic accidents, if the provided infrastructure is unsatisfactory. Overall health effects will depend on the severity of the injuries sustained from these potential accidents relative to the health benefits accruing from increased exercise.	[-1,+1]	limited	high	*medium*
	Health Care Provision (3.7/3.8)	Aranda et al. (2014)	Access to modern energy services can facilitate improved health care provision, medicine and vaccine storage, utilization of powered medical equipment, and dissemination of health-related information and education. Such services can also enable thermal comfort in homes and contribute to food preservation and safety.	[+1]	limited	medium	*medium*
	Air Pollution (3.9)	Rose et al. (2014): Chaturvedi and Shukla (2014); Rafaj et al. (2013); Riahi et al. (2012); IEA (2016); Nemet et al. (2010), West et al. (2013); Rao et al (2013); Rao et al (2016); Haines et al. (2007); van Vliet et al. (2012); Smith and Sagar (2014); Anenberg et al. (2013); Kaygusuz (2011)	Promoting most types of renewables and boosting efficiency greatly aid the achievement of targets to reduce local air pollution and improve air quality; however, the order of magnitude of the effects, both in terms of avoided emissions and monetary valuation, varies significantly between different parts of the world. Benefits would especially accrue to those living in the dense urban centers of rapidly developing countries. Utilization of biomass and biofuels might not lead to any air pollution benefits, however, depending on the control measures applied. In addition, household air quality can be significantly improved through lowered particulate emissions from access to modern energy services.	[+2]	robust	high	*very high*
4 QUALITY EDUCATION	Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)	van de Walle et al. (2013); Lipscomb et al. (2013)	Access to modern energy is necessary for schools to have quality lighting and thermal comfort, as well as modern information and communication technologies. Access to modern lighting and energy allows for studying after sundown and frees constraints on time management that allow for higher school enrollment rates and better literacy outcomes.	[+1]	limited	high	*medium*
	Human Capital (4.4/4.6/4.7)	Gustavsson (2007); ESMAP (2003); Khandker et al. (2009)	Quality education throughout a society (i.e., more and better trained teachers) raises its general level of human capital. This collection of knowledge and skills can then be drawn upon to promote sustainable development, potentially influencing the technological, financial, and political solutions that are feasible to implement, for example in the energy sector.	[+1]	robust	high	*high*
5 GENDER EQUALITY	Women's Safety and Worth (5.1/5.2/5.4)	Haves (2012); Anenberg et al. (2013); Pachauri and Rao (2013); Matinga (2012); Chowdhury (2010);	Improved access to electric lighting can improve women's safety and girls' school enrollment. Cleaner cooking fuel and lighting access can reduce health risks and drudgery, which are disproportionately faced by women.	[+1]	medium	medium	*medium*
	Opportunities for Women (5.1/5.5)	Dinkelman (2011); Clancy et al (2011); Kohlin et al. (2011); Kaygusuz (2011); Pachauri and Rao (2013); Haves (2012); Chowdhury (2010);	Access to modern energy services has the potential to empower women by improving their income-earning and entrepreneurial opportunities and reducing drudgery. Participating in energy supply chains can increase women's opportunities and agency and improve business outcomes.	[+1]	medium	medium	*medium*
	Reproductive Rights of Women (5.6)	Jensen and Oster (2009)	Energy access-enabled ICT services can potentially also reduce the risk of violence against women and improve fertility outcomes.	[+1]	limited	medium	*low*

6 CLEAN WATER AND SANITATION	Water Availability (6.1/6.2/6.4/6.5/6.6)	Davies et al. (2013); Byers et al. (2014); Fricko et al. (2016); Vidic et al. (2013); Miara et al. (2014); PBL (2012); Hanasaki et al. (2013); Hejazi et al. (2013); Fujimori et al. (2016)	An up-scaling of renewables and energy efficiency will, in most instances, reinforce targets related to water access, scarcity and management by lowering water demands for thermal cooling at energy production facilities ('water-for-energy'), compared to less-efficient fossil energy technologies. However, bioenergy and hydropower technologies could, if not managed properly, have counteracting effects that compound existing water-related problems in a given locale. In the reverse direction, today's water pumping, conveyance, and treatment systems require a considerable amount of energy for operation ('energy-for-water'). Expanding these services to poorer populations will be enabled by universal energy access provision.	[+2]	robust	high	***very high***
		Strbac (2008); Parkinson et al. (2016)	Increased shifts toward unconventional water supply options, such as desalination, in the world's water-stressed regions will generally increase energy demand. This could either be to the benefit of renewables (if water-related infrastructure and equipment can be used for real-time demand-side power management, thus helping with integration of the intermittent sources of electricity) or could present a marked challenge to their deployment (if there are constraints to up-scaling renewables quickly).	[-1,+1]	limited	high	***medium***
	Water Quality (6.3/6.6)	Davies et al. (2013); Fricko et al. (2016); Vidic et al. (2013); Miara et al. (2014); Haines et al. (2007)	An up-scaling of renewables and energy efficiency should lead to lower levels of water pollution (chemical and thermal) than a fossil-dominant energy system. The impacts of bioenergy deployment will need to be evaluated on a case-by-case basis, however.	[+2]	robust	high	***high***
8 DECENT WORK AND ECONOMIC GROWTH	Employment Opportunities (8.2/8.3/8.5/8.6)	Pueyo et al. (2013); Rao (2013); Grogan and Sadanand (2013); Bernard and Torero (2015); Chakravorty et al. (2014)	Provision of energy access can play a critical enabling role for new productive activities, livelihoods and employment. Reliable access to modern energy services can have an important influence on productivity and earnings.	[+1]	medium	high	***medium***
		Gohin (2008); Creutzig et al. (2013); Ferroukhi et al. (2016); Frondel et al. (2010); Borenstein (2012); Guivarch et al. (2011); Babiker and Eckaus (2007); Fankhauser et al. (2008); Clarke et al. (2014); Aether (2016); Blyth et al. (2014); Bertram et al. (2015); Johnson et al. (2015); Dechezleprêtre and Sato (2014); Jackson and Senker (2011); Dinkelman (2011)	Deploying renewables and energy-efficient technologies, when combined with other targeted monetary and fiscal policies, can help spur innovation and reinforce local, regional, and national industrial and employment objectives. Gross employment effects seem likely to be positive; however, uncertainty remains regarding the net employment effects due to several uncertainties surrounding macro-economic feedback loops playing out at the global level. Moreover, the distributional effects experienced by individual actors may vary significantly. Strategic measures may need to be taken to ensure that a large-scale switch to renewable energy minimizes any negative impacts on those currently engaged in the business of fossil fuels (e.g., government support could help businesses re-tool and workers re-train).	[-1,+2]	medium	low-medium	***medium***
	Innovation and Growth (8.1/8.2/8.4)	Clarke et al. (2014); Jackson and Senker (2011); York and McGee (2017); OECD (2017); New Climate Economy (2014); Bonan et al. (2014)	Decarbonization of the energy system through an up-scaling of renewables and energy efficiency is consistent with sustained economic growth and resource decoupling. Long-term scenarios point towards slight consumption losses caused by a rapid and pervasive expansion of such energy solutions. Whether sustainable growth, as an overarching concept, is attainable or not is more disputed in the literature. Existing literature is also undecided as to whether or not access to modern energy services causes economic growth.	[0]	medium	medium	***medium***
	Strong Financial Institutions (8.10)	Schmidt (2014); DB Climate Change Advisors (2011); Bhattacharyya (2013); Muench et al. (2016); WBGU (2012)	To support clean energy and energy efficiency efforts, strengthened financial institutions in developing country communities are necessary for providing capital, credit, and insurance to local entrepreneurs attempting to enact change.	[+1]	robust	high	***high***
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Inclusive and Sustainable Industrialization (9.2/9.4)	Fankhauser et al. (2008); Guivarch et al. (2011); Bertram et al. (2015); Johnson et al. (2015)	A rapid up-scaling of renewable energies could necessitate the early retirement of fossil energy infrastructure (e.g., power plants, refineries, pipelines) on a large-scale. The implications of this could in some cases be negative, unless targeted policies can help alleviate the burden on industry.	[0,-1]	medium	high	***medium-high***
	Infrastructure renewal (9.1/9.3/9.5)	Riahi et al. (2012); Goldthau (2014); Bhattacharyya et al. (2016); Meltzer (2016)	Financial and technical support can play a critical role in promoting the development of the renewable energy industry and more energy-efficient infrastructure. This includes targeted policy incentives (e.g., subsidies) and spending on scientific research to encourage technological innovation.	[+2]	robust	high	***high***
			Transitioning to a more renewably-based energy system that is highly energy efficient is well alighed with the goal of upgrading energy infrastructure and making the energy industry more sustainable. In the reverse direction, infrastructure upgrades in other parts of the economy, such as modernized telecommunication networks, can create the conditions for a successful expansion of renewable energy and energy efficiency measures (e.g., smart-metering and demand-side management).	[+1]	medium	medium	***medium***
10 REDUCED INEQUALITIES	Empowerment and Inclusion (10.1/10.2/10.3/10.4)	Pachauri et al. (2012); Pueyo et al. (2013); Dinkelman (2011);	Energy efficiency measures and the provision of energy access can free up resources (e.g., financial, time savings) that can then be put towards other productive uses (e.g., educational and employment opportunities), especially for women and children in poor, rural areas.	[+1]	robust	medium	***medium***
		Cameron et al. (2016); Jakob and Steckel (2014); Casillas and Kammen (2012); Hallegate et al. (2016); Fay et al. (2015); Hirth and Ueckerdt (2013)	The distributional costs of new energy policies (e.g., supporting renewables and energy efficiency) are dependent on instrument design. If costs fall disproportionately on the poor, then this could work against the promotion of social, economic and political equality for all.	[0,-1]	robust	high	***high***
		Kunze and Becker (2015); Cumbers (2012); Walker and Devine-Wright (2008); Cass et al. (2010)	Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities.	[+1]	medium	medium	***medium***
		Cayla and Osso (2013)	The impacts of energy efficiency measures and policies on inequality can be both positive (if they reduce energy costs) or negative (if mandatory standards increase the need for purchasing more expensive equipment and appliances).	[-1,+1]	limited	low	***low***
11 SUSTAINABLE CITIES AND COMMUNITIES	Housing and Transport (11.1/11.2)	Bhattacharya et al. (2016); UN (2016)	Ensuring access to basic housing services implies that households have access to modern energy forms.	[+3]	robust	high	***very high***
			Efficient transportation technologies powered by renewably-based energy carriers will be a key building block of any sustainable transport system.	[+2]	robust	high	***very high***
	Urban Environmental Sustainability (11.3/11.6)	Riahi et al. (2012); Kahn Ribeiro et al. (2012); Grubler and Fisk (2012); Creutzig et al. (2012); Bongardt et al. (2013); Raji et al. (2015)	Renewable energy technologies and energy-efficient urban infrastructure solutions (e.g., public transit) can also promote urban environmental sustainability by improving air quality and reducing noise.	[+2]	medium	high	***very high***
	Disaster Preparedness and Prevention (11.5)	Riahi et al. (2012); IPCC (2014); Daut et al. (2013); Tully (2006); Hallegatte et al. (2016)	Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of people to certain types of disasters and extreme events.	[+2]	medium	high	***high***
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Natural Resource Protection (12.2/12.3/12.4/12.5)	Banerjee et al. (2012); Riahi et al. (2012); Bhattacharyya et al. (2016); Cameron et al. (2016); Schwanitz et al. (2014)	Renewable energy and energy efficiency slow the depletion of several types of natural resources, namely coal, oil, natural gas, and uranium. In addition, the phasing-out of fossil fuel subsidies encourages less wasteful energy consumption; but if that is done, then the policies implemented must take care to minimize any counteracting adverse side-effects on the poor (e.g., fuel price rises).	[+2]	robust	high	***very high***
	Sustainable Practices and Lifestyles (12.6/12.7/12.8)	New Climate Economy (2015); European Climate Foundation (2014); CDP (2015); Stefan and Paul (2008); Khan et al. (2015)	Sustainable practices adopted by public and private bodies in their operations (e.g., for goods procurement, supply chain management, and accounting) create an enabling environment in which renewable energy and energy efficiency measures may gain greater traction.	[+1]	robust	high	***high***

13 CLIMATE ACTION	Climate Strategies and Education (13.2/13.3)	Jennings (2009); Schreurs (2008); IPCC (2011)	Better integrating climate change measures into national planning and improving education, awareness, and capacity on climate issues will go a long way in furthering international targets for renewables and energy efficiency.	[+2]	robust	high	***high***
	Global Warming (*)	Kriegler et al. (2014); Kriegler et al. (2013); Riahi et al. (2015); Riahi et al. (2017); Tavoni et al. (2013); Gambhir et al. (2017); PBL (2012); Rogelj et al. (2013); Anenberg et al. (2013)	Meeting the renewable energy and energy efficiency targets of SDG7 is a necessary, but not entirely sufficient, condition for long-term temperature stabilization below 2 °C. For the latter to be achieved with high probability, an up-scaling of efforts beyond 2030 will be needed. Providing universal access to modern energy services by 2030 is fully consistent with the Paris Agreement, as reaching this target will have only a minor effect on global carbon emissions. *[*Note: The 2030 Agenda text describing SDG13 does not specifically mention a long-term temperature goal, but it does refer to the UNFCCC process, and the stated objective of the 2015 Paris Agreement is "well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C".]*	[0,+2]	robust	high	***very high***
14 LIFE BELOW WATER	Marine Protection (14.1/14.2/14.4/14.5)	WBGU (2013); Inger et al. (2009)	Depending on the local context and prevailing regulations, ocean-based energy installations could either induce spatial competition with other marine activities, such as tourism, shipping, resources exploitation, and marine and coastal habitats and protected areas, or provide further grounds for protecting those exact habitats, therefore enabling marine protection.	[-1,+1]	limited	high	***medium***
	Ocean Acidification (14.3)	Le Quére et al. (2009); WBGU (2013); Feely et al. (2009); Caldeira and Wicket (2003); Gruber (2011); The Royal Society (2005)	Deployment of renewable energy and improvements in energy efficiency globally will aid climate change mitigation efforts, and this, in turn, can help to slow rates of ocean acidification.	[+2]	robust	high	***high***
	Marine Economies (14.7)	WBGU (2013); Buck and Krause (2012); Michler-Cieluch et al. (2009)	Ocean-based energy from renewable sources (e.g., offshore wind farms, wave and tidal power) are potentially significant energy resource bases for island countries and countries situated along coastlines. Multi-use platforms combining renewable energy generation, aqua-culture, transport services and leisure activities can lay the groundwork for more diversified marine economies.	[+1]	limited	high	***low***
15 LIFE ON LAND	Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)	Karekezi et al. (2012); Bazilian et al (2011); Winter et al. (2015); Bailis et al. (2015)	Ensuring that the world's poor have access to modern energy services would reinforce the objective of halting deforestation, since firewood taken from forests is a commonly used energy resource among the poor.	[+2]	medium	high	***high***
		Smith et al. (2014); Smith et al. (2010)	Protecting terrestrial ecosystems, sustainably managing forests, halting deforestation, preventing biodiversity loss and controlling invasive alien species could potentially clash with renewable energy expansion, if that would mean constraining large-scale utilization of bioenergy or hydropower. Good governance, cross-jurisdictional coordination, and sound implementation practices are critical for minimizing trade-offs.	[0,-2]	limited	high	***medium***
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Institutional Capacity and Accountability (16.1/16.3/16.5/16.6/16.7/16.8)	ICSU, ISSC (2015); Acemoglu (2009); Acemoglu et al. (2014); Tabellini (2010)	Institutions that are effective, accountable, and transparent are needed at all levels of government (local to national to international) for providing energy access, promoting modern renewables, and boosting efficiency. Strengthening the participation of developing countries in international institutions (e.g., international energy agencies, United Nations organizations, World Trade Organization, regional development banks and beyond) will be important for issues related to energy trade, foreign direct investment, labor migration, and knowledge and technology transfer. Reducing corruption, where it exists, will help these bodies and related domestic institutions maximize their societal impacts. Limiting armed conflict and violence will aid most efforts related to sustainable development, including progress in the energy dimension.	[+2]	robust	high	***very high***
17 PARTNERSHIPS FOR THE GOALS	International Cooperation (17.1/17.3/17.4/17.5/17.6/17.7/17.8/17.9/17.10/17.11/17.12/17.15/17.16/17.17/17.18/17.19)	Clarke et al. (2009); Riahi et al. (2015); Riahi et al. (2017); O'Neill et al. (2017); New Climate Economy (2015); Eis et al. (2016); Ramaker et al. (2003); Montreal Protocol (1989)	International cooperation (in policy) and collaboration (in science) is required for the protection of shared resources. Fragmented approaches have been shown to be more costly. Specific to SDG7, to achieve the targets for energy access, renewables, and efficiency, it will be critical that all countries: (i) are able to mobilize the necessary financial resources (e.g., via taxes on fossil energy, sustainable financing, foreign direct investment, financial transfers from industrialized to developing countries); (ii) are willing to disseminate knowledge and share innovative technologies between each other; (iii) follow recognized international trade rules while at the same time ensuring that the least developed countries are able to take part in that trade; (iv) respect each other's policy space and decisions; (v) forge new partnerships between their public and private entities and within civil society; and (vi) support the collection of high-quality, timely, and reliable data relevant to the furthering their missions. There is some disagreement in the literature on the effect of some of the above strategies, such as free trade. Regarding international agreements, "no-regrets options", where all sides gain through cooperation, are seen as particularly beneficial (e.g., nuclear test ban treaties).	[0,+2]	medium	medium	***medium***

Context-dependencies and the nature of SDG interactions

To be sure, the realm of SDG interactions is not always defined by universal truths: the nature of a given linkage is context-dependent, often case-specific. Thus, when assessing interactions for the purposes of real-world policy implementation, it will be important for scientists to clearly articulate what the interactions depend on, as we have done in several places in Table 2. Considerations of time, geography, governance, technology, and directionality are particularly important in this regard:

- *Time* || Certain interactions play out in real time, whereas the impacts of others materialize only after significant time lags.
- *Geography* || Policies enacted in one location may result in major impacts between different SDGs, but in another location have very little, or no, impact.
- *Governance* || How a policy is implemented (by which instruments and the nature of coordination between government institutions and levels of government) is a determining factor in its ultimate effect.
- *Technology* || There may be a real trade-off between SDGs given current technological limitations; but when advanced technologies are deployed, the trade-offs may be suppressed, if not eliminated.
- *Directionality* || The interaction between two SDGs can be (i) unidirectional or bidirectional and (ii) symmetrical or asymmetrical.

In the Supplementary Discussion, we elucidate how context dependencies shape the nature of interactions between SDG7 (Energy) and six other SDGs, namely: SDG1 (No Poverty), SDG2 (Zero Hunger), SDG3 (Good Health and Well-Being), SDG6 (Clean Water and Sanitation), SDG8 (Decent Work and Economic Growth), and SDG13 (Climate Action).

Insights relevant for the scientific community

Based on our reading of the relevant literature, the energy-related interactions among certain SDG dimensions are better understood than others (see rightmost column of Table 2). For these, we are able to conclude with ‘high’ or ‘very high’ confidence how those interactions are likely to play out in the future. More specifically, there appears to be considerable agreement within the existing scientific evidence base that ensuring universal energy access to the poor, deploying most types of renewables at large-scale and/or boosting energy efficiency efforts will have positive impacts on – or will be aided by – the targets for achieving poverty alleviation (SDG1), better human health (SDG3), greater water availability and quality (SDG6), enhanced sustainability of cities (SDG11), natural resources protection (SDG12), reduced climate change (SDG13), and strong and just institutions (SDG16). On the other hand, we find lower agreement in the literature for – and therefore assign lower levels of confidence to – the energy-related interactions among the other SDGs. For instance, it is not entirely clear how a transition from a fossil- to a renewable-based energy system globally will affect the labor markets of individual countries and regions (SDG8) or will impact local-scale marine economies (SDG14). And to be sure, even for the SDGs where fewer knowledge gaps exist, there may be sub-dimensions where additional research would be important. For example, the overall impact of 'active travel modes' (walking and cycling) is in need of further study, in order to understand the role that good governance (in the form of quality infrastructure provision) can play in ensuring that this city-level energy efficiency strategy does more to improve people's health than to put them at greater risk of road traffic accidents (SDG3). This highlights the complexities inherent in the SDGs: to truly appreciate them, one must dive down to the target level.

There are several reasons why uncertainty remains for some of the interactions highlighted in Table 2. And there are numerous strategies the scientific community can employ to better its understanding of these areas going forward. Firstly, the context-dependencies listed previously make it difficult to draw generalizable conclusions about interactions that may ultimately depend on locally-specific factors. An example would be the impact of energy access provision on creating employment and educational opportunities for women (SDG5, SDG10): the effect could certainly be positive, but much depends on how rigid the cultural norms are within the prevailing society. Secondly, appropriate scientific tools are less mature for studying some SDG dimensions, especially tools of the quantitative variety. For instance, as far as we are aware, no energy systems or integrated assessment models capture the feedback effects between educational attainment and renewables, efficiency and energy access in an endogenous way. The shared socioeconomic pathways (SSPs) took a healthy step in this direction (KC and Lutz, 2017), but more could be done.

Filling the knowledge gaps delineated here demands that scientists from different disciplines share knowledge and collaborate on a scale not seen before. The expertise of energy researchers from a wide variety of fields must be leveraged for this purpose, including, but not limited to: social scientists (sociologists, anthropologists, demographers, human geographers, political scientists, economists, urban planners, and experts in education, law and communications); natural scientists (biologists, hydrologists, oceanographers, atmospheric chemists, and experts in climate, health and agricultural studies); engineers (across the spectrum); and integrated systems modelers, to name just a few. If those collaborations can be realized, and if they turn out to be fruitful, then the evidence base on energy-related SDG interactions should grow quickly. With any luck, it should then be possible to conduct an even deeper assessment of these interactions within a few years' time, perhaps as part of a full-scale 'SDG interactions assessment report' akin to the regular climate science assessments coordinated by the Intergovernmental Panel on Climate Change (IPCC). Alternatively, given that an assessment of this nature would be a massive undertaking, one could also imagine smaller reports, conducted over shorter time intervals, that partition the SDGs into clusters. The *economic-social-environmental* framing could be utilized for this purpose, or perhaps even the thematic groupings the UN's High-level Political Forum is already making use of in its ‘revolving-door’ review of the SDGs over the next two years (sustainabledevelopment.un.org/hlpf). Deeper collaboration between research communities could also give scientists a louder voice in the ongoing SDG discourse, particularly as the process moves from the Goal-setting to the implementation and monitoring/evaluation phases. This will demand the building of integrative, multi-dimensional assessment systems geared toward assessing the outcomes and impacts of the various measures put in place across the spectrum of SDGs.

Insights relevant for policy-making

The overarching take-away from Table 2 is that the three targets of SDG7 (Energy) are, in one way or another, linked to those underpinning each of the other 16 SDGs. One conclusion then, from a practical policy-making perspective, is that new methods need to be employed in assessing the multi-dimensional outcomes and impacts of proposed instruments, projects and plans (i.e., the means of policy implementation). Interdisciplinary science must provide the analytical backbone for such assessments. Moreover, it is clear that the ‘silo approach’ to policy-making, as traditionally applied in countries the world over, is no longer suitable as a mechanism for effecting systemic change. A paradigm shift to policy and institutional frameworks that take an integrated, holistic perspective is long overdue. For this to happen effectively, pro-active engagement and enhanced coordination across government departments and ministries, as well as across different levels of government (from international to national to local), will be required. Integrated planning institutions within countries could play an important role here, bridging the knowledge and plans of seemingly disparate government ministries that have for decades been tasked with handling policy objectives in a more isolated way. (These are some of the motivations behind, for example, Colombia’s ‘Integrating Approach’ [communitascoalition.org/pdf/Integrating_Approach_7OCT2013.pdf] and Ethiopia’s ‘Climate-Resilient Green Economy vision’ [www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf].) Failing a major push toward policy integration, the silo approach could persist indefinitely. This would not serve the achievement of the SDGs well.

Integrated, holistic thinking on policy may also serve as a strong motivator for action along individual SDG dimensions. On the one hand, for instance, improving air quality and bettering human health (SDG3) are major concerns of local policy-makers in India and China. Thus, a better appreciation for how energy-focused climate change mitigation actions (SDG13) impact air pollutant emissions might ultimately incentivize even stronger energy-climate policies than if climate change were the only concern. Put differently, countries might consider ratcheting up their internationally-agreed carbon reduction pledges – their Nationally Determined Contributions (NDCs) – based on national/local concerns. Given that pledged actions to date are far too lenient for keeping global temperatures well below 2 °C over the long term (Rogelj et al., 2016), having this added incentive to reduce carbon emissions would not be particularly bad.

Incidentally, the Chinese government already seems to realize this, with respect to the air quality improvements they aim to achieve as a result of their policies for phasing out fossil energy (Buckley, 2013). Meanwhile, the Indian government is targeting energy access policies as a means to improve the health of the rural poor (Smith, 2016). To be sure, energy solutions along one SDG dimension could also impose risks of trade-offs, as highlighted in Table 2. Government-supported strategies and measures should therefore strive to minimize, or avoid, such negative interactions between SDGs, while ensuring that where positive ones exist, they materialize as frequently as possible and their full potential is tapped.

Conclusions

We appreciate that, with the arrival of the UN's *2030 Agenda*, the notion of integrated and holistic thinking has entered into the global policy discourse in a highly visible way. Moving toward action now requires a surge of support from the scientific community, in order to ensure that a greater recognition of SDG interactions actually does drive policy practitioners toward socially desirable development pathways. In this Perspective, we report on a systematic assessment of the relevant energy literature (Table 2), which we conducted to better our understanding of how key energy-related interactions between SDGs might play out globally. Based on the nature of the interactions we identified, and our evaluation of the confidence that can currently be assigned to each of those interactions, we arrive at several conclusions relevant for both the scientific and policy-making communities. First, our analysis indicates that positive interactions between SDG7 (Energy) and the other SDGs clearly outweigh the negative ones, both in number and magnitude (Figure 1). Second, in order to fill knowledge gaps in critical areas, we argue that there is an urgent need for scientists from different disciplines to share knowledge and collaborate on a scale not seen before. This could lead to, indeed even require, new data, scientific tools, and fresh perspectives to support original analyses. According to our analysis of the literature, an improved understanding is needed for how achievement of the SDG7 (Energy) targets interacts with SDG2 (Zero Hunger), SDG4 (Quality Education), SDG5 (Gender Equality), SDG8 (Decent Work and Economic Growth), SDG9 (Industry, Innovation and Infrastructure), SDG10 (Reduced Inequalities), SDG14 (Life Below Water), and SDG15 (Life on Land). Third, policymakers must do more than simply acknowledge the mere existence of SDG interactions; they also need to mobilize additional resources and implement new laws and planning and evaluation methodologies. With respect to energy policy in particular, the choice of policy instrument and design needs to be made carefully, so that the effects on other sustainability dimensions are as intended (e.g., renewable energy policies should not be allowed to drive up energy prices for the poor, unless redistributional fuel price support mechanisms are simultaneously put in place). Moreover, wider efforts to promote policy coherence and integrated assessments are required to address potential policy spillovers across sectors, sustainability domains, and geographic and temporal boundaries. Policy-makers would thus do well to ensure that their particular country's institutions engage in inclusive practices that cut across government bodies during all phases of policy planning, implementation, monitoring and assessment. Institutional reforms that usher out last century's favored governing model, the siloed approach, are needed more than ever. In our opinion, energy is a logical place to start on this path, given how deeply woven it is into the fabric of the SDGs. 'Doing energy right' is fundamental to the success of the *2030 Agenda*; and as we demonstrate in this Perspective, energy scientists have a major role to play in offering guidance to the discourse.

Additional information

Correspondence should be addressed to D.L.M. (mccollum@iiasa.ac.at).

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