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Insights

全球可再生能源趋势

太阳能和风能已成首选

目录

总结

种种迹象表明，可再生能源已经成为主流优选能源方案。受电网平价、并网以及技术三大关键驱动因素影响，太阳能与风能可逐渐与传统能源并驾齐驱。与此同时，由于可再生能源价格实惠、低碳环保且稳定可靠，城市、社区、新兴市场和企业等广大消费者的可再生能源需求不断提升。这些驱动因素和需求趋势在全球发达和发展中地区尤为明显。

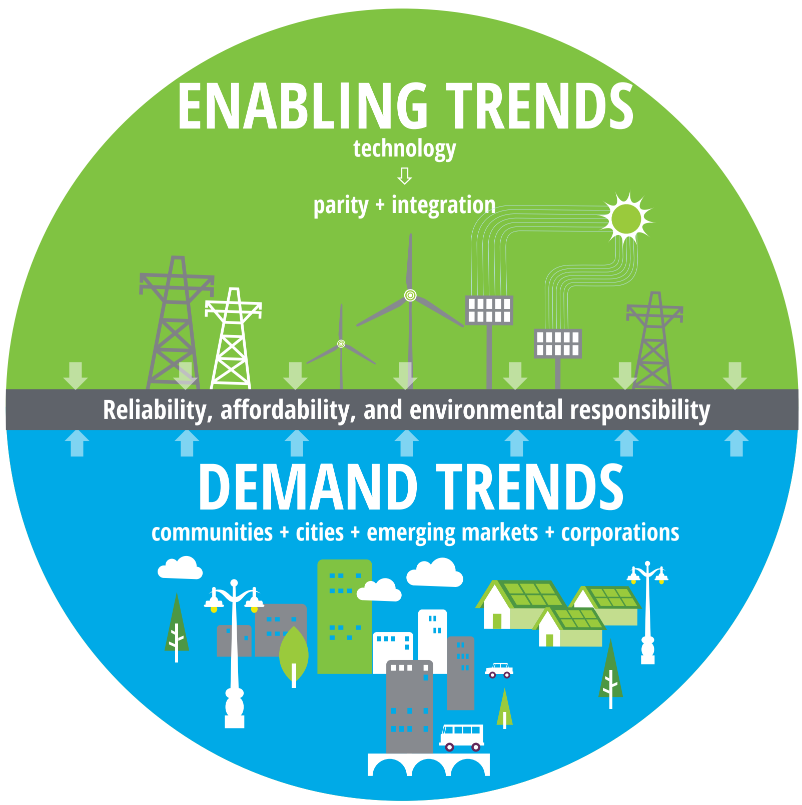
首先，可再生能源逐步实现并网和离网的价格和性能持平。第二，太阳能和风能能够经济实惠地并网并提升可靠性。第三，新科技不断优化风能和太阳能。在此推动下，太阳能与风能的价格和效能可与传统能源一较高下，脱颖而出。

Renewable energy is rapidly becoming a preferred “mainstream” energy source.

三大关键因素使可再生能源能够最有效地实现能源消费者的三大需求。尽管对需求的侧重程度不同，但消费者均在寻求最实惠、最低碳的可靠能源资源。其中主要的消费者包括：将可再生能源纳入其智慧城市计划的城市；开展能源项目，通过并网和离网可再生资源惠及大众的社区；引领可再生资源部署推动城市发展的新兴市场；以及不断扩大太阳能与风能采购范围的企业。

FIGURE 1

Renewables are best able to meet demand for reliable, affordable and environmentally responsible energy



Source: Deloitte analysis.

关键驱动因素

长期以来，可再生能源的大规模部署面临着重重障碍，而在电网平价、积极并网和技术创新三大关键驱动因素的影响下，这些障碍正日渐消弭。太阳能和风能曾被认为太昂贵而难以大范围采用，而目前其正在凭借高性价比打败传统资源。随着太阳能和风能并网能够助力解决电网问题，可再生能源存在诸多亟待解决的并网问题这一观念已经发生转变。目前可再生能源可以充分利用先进技术超越传统能源，而无需等待配套技术成熟。

I. 实现并网和离网平价及性能持平

即便是最乐观的业内企业和观察人士，仍对太阳能和风能的部署步伐及其成本下降幅度之大感到惊讶。风能和太阳能不仅颠覆长久以来的印象，而且超出预期，在未获政府补贴的情况下也能在全球主要市场与传统发电技术展开竞争。

风能和太阳能已实现电网平价，其性能也逐步与传统能源不相上下。事实上，全球大部分地区，公用事业规模的海上风能与太阳能光伏发电在在未获政府补贴的情况下，平准化度电成本不断下降，与大多数其他发电技术持平或更低[1]。尽管联合循环燃气轮机等资源能够按需调配，但随着日益平价的蓄电池储能和其他创新技术逐步解决风能和太阳能的间歇性问题，风能和太阳能的可靠性不断提高，可与传统能源一较高下。从价格角度看，陆上风能已成为全球发电价格最低的能源资源，在未获政府补贴的情况下，其平准化度电成本为30美元至60美元，低于最便宜的化石燃料天然气价格区间（42美元至78美元）[2]。

截至2017年底，以中国、美国、德国、印度、西班牙、法国、巴西、英国和加拿大为首的121个国家共部署近485GW陆上风能[3]。而这九个国家均实现陆上风能电网平价[4]。美国大平原和德克萨斯州等风力强劲的地区风能发电成本最低，而东北部成本最高[5]。

从全球来看，前述九个领先国家地区、欧亚大陆和澳大利亚的风能发电成本最低[6]。公用事业规模的光伏太阳能发电成本也极其低廉，仅次于陆上风能。太阳能光伏的平准化度电成本上限区间为43美元至53美元/MWh，远低于任何其他发电能源[7]。2017年，全球187个国家新增发电装机容量创历史新高，达93.7GW，总容量达到386GW，中国、日本、德国、美国、意大利、印度和英国排名前列。其中，除日本外的其他国家市场均实现太阳能电网平价。因投资成本较高，日本成为全球太阳能发电成本最高的市场之一[8]。随着日本向竞争性拍卖过渡，太阳能电网平价有望于2025年至2030年期间实现[9]。

西南部各州和加利福利亚是美国太阳能光伏发电成本最低的地区[10]。从全球角度看，澳大利亚是太阳能光伏发电成本最低的国家，非洲因投资成本过高而成为成本最高的国家[11]。

随着风能和太阳能与其他发电能源之间的成本差距逐渐拉大，全球电网平价指日可待。过去八年中，除了联合循环燃气外，所有传统能源和非风能及太阳能可再生能源的平准化度电成本或保持平稳（生物质能和煤炭），或有所上升（地热能、水能和核能）。由于组件成本大幅下跌和效率的提升，且这两大趋势预计将持续下去，陆上风能和公用事业规模的太阳能光伏发电的平准化度电成本分别下跌67%和86%[12]。根据彭博新能源财经报道，2018年上半年，陆上风能和太阳能光伏发电成本已经下降18%[13]。

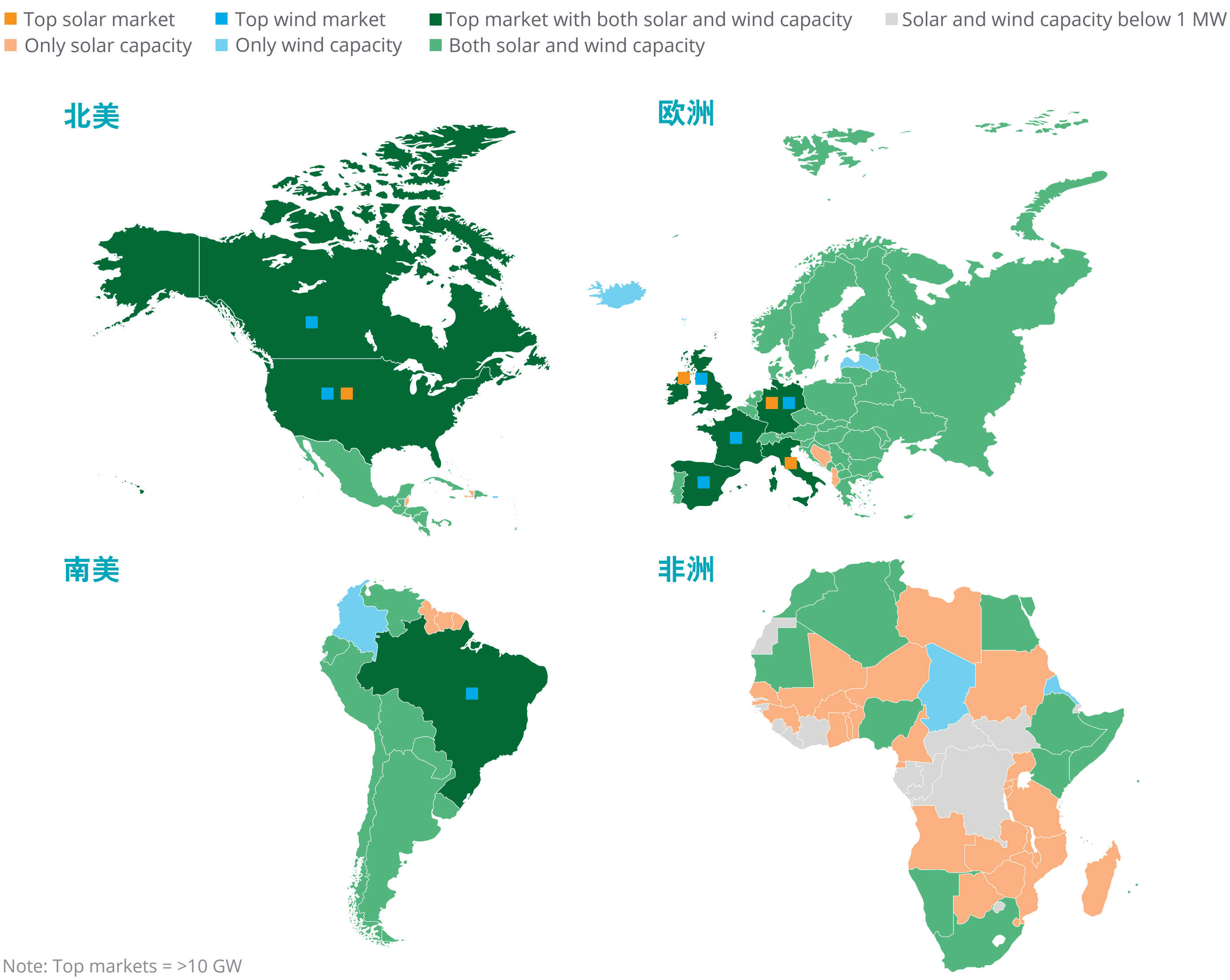
竞争性拍卖推动欧洲、日本和中国以较低价格且无补贴的方式开展发电部署，进一步推动发电成本降低[14]。发达国家通过风力涡轮机升级改造提高容量系数，促进全球平均发电成本降低[15]。此外，日本、德国和英国太阳能资源最匮乏但却是全球太阳能发电的领先国家，而非洲和南美洲分别拥有最丰富的太阳能和风能资源但大部分却尚未开发。随着全球开发公司和国际组织合作解决这一失衡问题，促进项目发展，发展中世界的发电成本将有所下降。风能和太阳能装机发电容量不断增大，许多传统能源将开始以较低容量系数运行，导致其平准化度电成本升高[16]。新太阳能和风能发电厂的成本最终将低于新建的传统发电厂，并低于全球现有发电厂继续运行的成本。意大利国家电力公司Enel去年成功赢取智利风能、太阳能和地热能综合发电厂项目就是有力证明。智利综合发电厂的电力销售价格将低于现有煤电厂和燃气发电厂的燃料成本[17]。

海上风能和聚光太阳能热发电也逐步实现电网平价，其平准化度电成本区间与煤电上限范围重合，但仍高于燃气联合循环方式[18]。2017年，全球15个国家共4.9GW的海上风能装机容量上线运行，创历史纪录，总容量达19.3GW，而大部分位于英国、德国、中国和丹麦[19]。德国和丹麦已实现海上风能电网平价，英国预计将于2025年至2030年期间实现，中国预计到2024年实现[20]。美国仅有一座海上风电场，但项目资源不断增多，其中大多数位于竞争激烈的北大西洋沿岸地区[21]。随着越来越多项目的部署，美国海上风能的平准化度电成本有望降至欧洲和中国的成本区间，且其海上风能预计在未来十年内实现电网平价[22]。在聚光太阳能热发电方面，西班牙（2.3GW）和美国（1.8GW）引领15个国家共4.9GW的市场，但两个国家分别从2013年和2015年起就未新增装机发容量[23]。中国和南澳大利亚的平准化度电成本最低[24]。聚光太阳能热发电目前均未实现电网平价，但近期一系列创历史新低的拍卖结果表明，这一发电方式能在2020年与化石燃料展开竞争[25]。聚光太阳能热发电还可进行储能，因此其性能可以达到传统能源资源相同水平。

可储能的公用事业规模太阳能和风能竞争力不断增强，除了电网平价后还推动实现电网性能持平。风能和太阳能的可调度性大幅提升，从而弥补了其相较于传统能源的固有短板。尽管具备储能功能的可再生能源成本较高，但却可以提供装机发电量和辅助电网服务，从而提升自身价值。自2010年起，锂离子电池成本下降近80%，太阳能普及率提高，推动这种组合模式实现电网平价[26]。由于具有储能功能，所有重点太阳能市场均开展了包含储能的公用事业规模项目[27]。在美国，作为储能市场的领先领域，太阳能储能已经在部分市场具备一定竞争力，电力开发公司Lightsource宣布将在其西部地区的所有竞标项目中包含储能[28]。基于投资税减免，美国明年初将在亚利桑那州实现太阳能储能项目平价，其次是内华达和科罗拉多，这些州还将实现风能储能平价[29]。落基山研究所近期一项研究表明，可再生能源储能可结合分布式资源和需求响应，建立清洁能源组合，以低于目前新建燃气电厂成本的价格提供

图 2

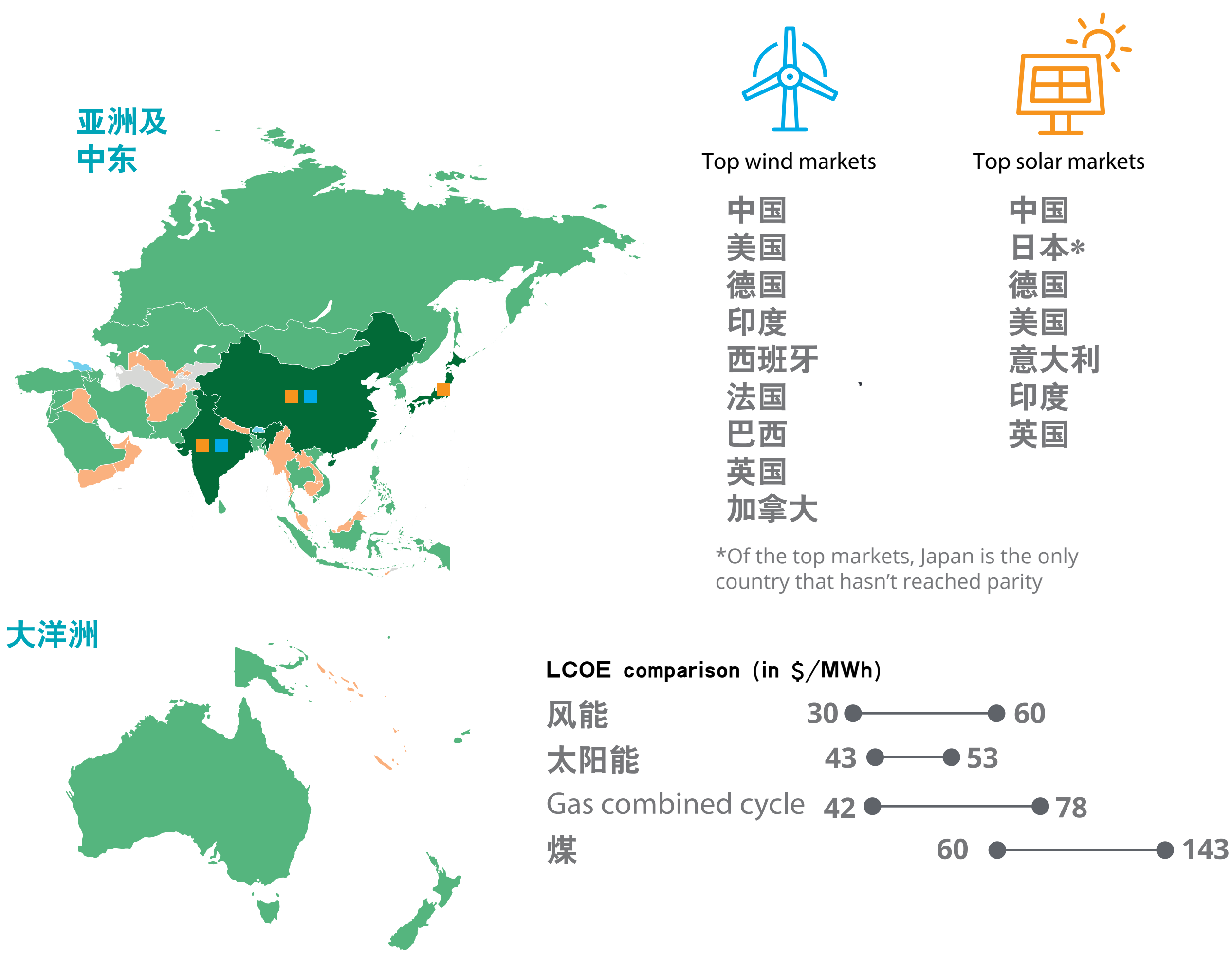
全球风能和太阳能装机发电容量及电网平价分布图。仅有太阳能装机发电容量的所有国家



Note: Top markets = >10 GW
Source: Map based on IRENA, *Renewable Capacity Statistics 2018*; LCOE comparison based on Lazard, *Levelized cost of energy analysis—version 11.0*, November 2017.

相同电网服务，且最早能在2026年实现价格低于现有发电厂的运行成本[30]。

随着屋顶太阳能等分布式可再生能源逐步实现离网平价和性能持平，公用事业规模的电网平价并非唯一考虑方案。在这种情况下，自行发电成本低于零售电费时将实现电网平价。商业太阳能光伏在电网平价的部分重点太阳能市场实现了离网平价且未获补贴，印度除外[31]。政府激励政策也促使住宅太阳能光伏发电在这些市场具有一定竞争力，到2020年初，加利福尼亚州将强制要求新建相关设施[32]。太阳能装置安装公司不断融合蓄电池储能和住宅太阳能。今年第一季度，美国家庭安装的住宅储能系统是过去三年的总和，大部分位于加利福尼亚州和夏威夷[33]，住宅太阳能储能目前低于19个州的费率。而在澳大利亚和德国的部分地区，2017年安装的住宅太阳能光伏系统中分别有40%和50%含储能功能[34]。澳大利亚和欧洲的住宅和商业屋顶太阳能装机容量高于公共太阳能装机发电容量，将在电网和离网平价实现时，极可能引发分布式和电网太阳能储能之间的能源之争。[35]

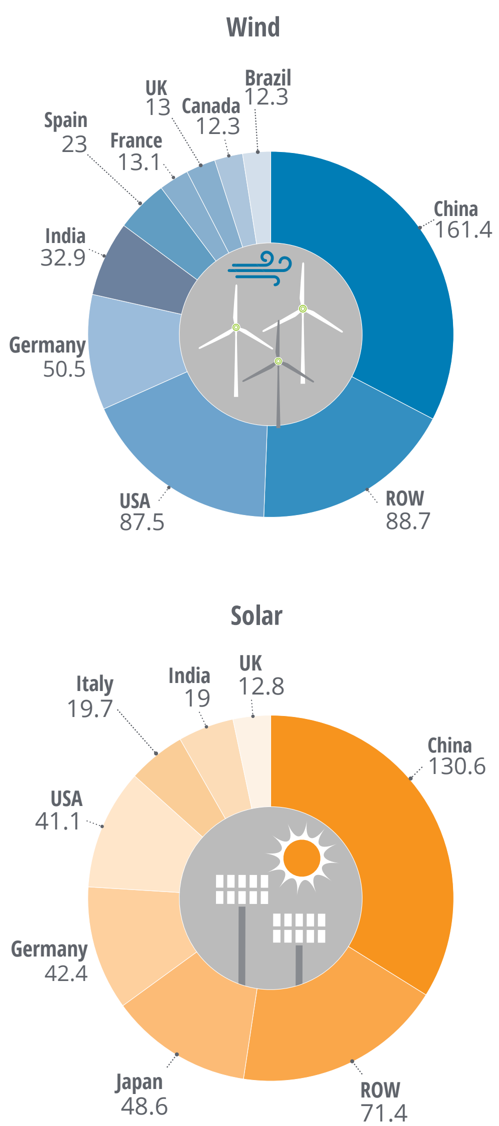


II. 实惠且可靠的并网

长期以来，间歇性一直被认为是制约太阳能和风能大规模部署的最主要障碍之一。目前，这一局势正在发生逆转：风能和太阳能将不再是亟待解决的问题，而是保障电网平衡的有效手段。事实上，可再生能源并网的难度和成本并不如预期高。此外，这些能源不仅促使电网更加灵活可靠，还可提供基本的电网服务。

FIGURE 3

Top onshore wind and solar PV markets



Note: Unit = GW

Source: IRENA, *Renewable capacity statistics 2018*.

风能和太阳能的间歇性问题可能被言过其实。多数国家和地区目前正处于可再生能源的普及阶段，要求对电网进行最低限度的调整：可再生能源较少进行系统层面登记，仅要求对运行方式和现有资源的使用做小幅变动[36]。在可再生能源普及率较高的国家或地区中，则要求更复杂的系统性改动，并对传统能源进行调整以促进可再生能源更大规模且更经济实惠地进行并网[37]。在欧盟、中国和印度，运营商改造热电联产电厂生产热而非电力，改造煤电厂和联合循环燃气轮机电厂以实现更灵活、更稳定的发电[38]。与临近市场互联是北欧成功推行的另一主要手段，也是加利福尼亚州ISO公司和西部能源平衡市场（Western Energy Imbalance Market）正考虑在美国采取的手段，原因在于如果可再生能源聚合方式普及至更多地区，则能够经济有效地解决产出电量并解决负荷削减量降低问题[39]。

风能和太阳能对电价构成下行压力。从理论上讲，由于边际发电成本为零，太阳能和风能可以置换更昂贵的发电机，且电价更低[40]。从全球看，太阳能部署促使午间价格峰值降低，同时降低了夜间电价[41]。美国太阳能和风能排名前20个州中，四分之三的州电价低于美国全国平均水平，四分之一属于电价最低的10个州，包括风能领先的德克萨斯州[42]。德国是欧洲最大的太阳能和风能市场，其批发价格在过去十年内下降过半[43]。丹麦拥有全球占比最高的间歇性可再生能源（53%），且其不含税费的电价全欧洲最低[44]。据劳伦斯伯克利国家实验室（Lawrence Berkeley National Laboratory）预计，一旦美国达到丹麦可再生能源的普及率（40%-50%），部分州将可能实现能源价格下降至极低水平[45]。

风能和太阳能的份额不断上升，其电网可靠性和灵活性也随之持续增强。美国停电频率最高的州很少甚至没有风能和太阳能，而停电最少的州属于太阳能和风能最强劲的州[46]。过去十年中，德克萨斯州的风力发电量增长645%，因此该州的电网可靠性指标得到大幅改善[47]。德国和丹麦的电网同样在过去十年中变得更为可靠，甚至一年中的五分之一时间内，丹麦为其西部地区贡献了90%的电力[48]。互联的丹麦和德国电网目前是全球电网最可靠的两个国家[49]。欧洲数据显示，非计划性停运占陆上和海上风电停运的较小比例，而大多数煤电厂和燃气发电厂停运均为非计划性。陆上风电停运几率较少且时间较短，恢复时间快于其他所有发电能源[50]。极端天气状况测试电网可靠性的情况下，可再生能源能够弥补燃料型能源的不足之处。2018年，暴风雪席卷英国，导致天然气短缺，而风能打破发电记录，超过2014年极地涡旋期间美国煤堆冻结以及2017年飓风哈维导致煤堆浸湿时的发电预期[51]。

Renewables have not been as difficult or costly to integrate as anticipated. What's more, they have demonstrated an ability to strengthen grid resilience and reliability and provide essential grid services.

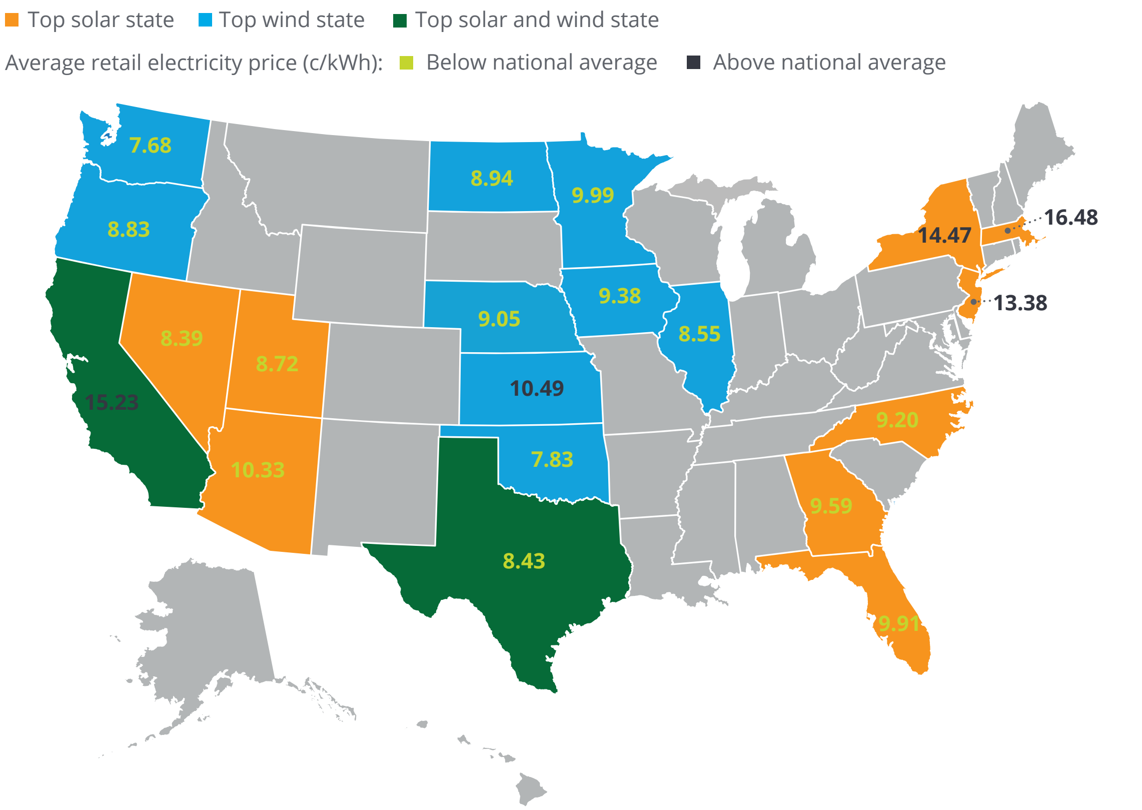
风电和太阳能将成为重要的电网资产。间歇性可再生能源有助于电网平衡。举例而言，2017年，风能降低了美国中西部独立系统运营商（MISO）北部大多数最陡峭的爬坡速率[52]。但实际上，传统发电仍继续提供与频率、电压和爬坡速率相关的所有基本电网可靠性服务[53]。然而这一局面将出现变化。借助智能逆变器与先进控制器，风能与太阳能亦能提供这些服务，甚至略胜一筹[54]。结合智能逆变器，风能与太阳能的调整速度较传统电厂更为迅速，并可在日落或风停后继续保持电网稳定，而且太阳能光伏的响应精准度亦远胜于其他能源[55]。智能逆变器还能将分布式资源转化为电网资产，对消费者的影响微乎其微，并推动这些资源用于公用事业[56]。能够运用这些能力的地区较少，但均对相关事宜做强制要求，并允许在市场上销售可再生能源配套服务和/或创建新的电力服务市场[57]。

其间，智能逆变器是助推可再生能源实现并网的技术之一。

FIGURE 4

Three quarters of the top 20 US solar and wind states have electricity prices below the US national average

All states have below-average electricity prices except for Massachusetts, California, New York, New Jersey, and Kansas



Note: The average retail price per kWh is 10.41 cents.

Source: GTM Research and SEIA, *US solar market insight, 2017 year in review*, 2018, p. 8; American Wind Energy Association, "Wind energy in the United States," 2018; US Energy Information Administration, "State electricity profiles," January 25, 2018 (data for 2016).

III. 促进可再生资源自动化、智能化、区块链化和转型的技术

自动化、人工智能、区块链、先进材料和先进制造等新技术加快可再生能源部署步伐。自动化和先进制造等技术改进可再生能源的生产和运营，人工智能进行天气预测，优化可再生能源的利用，区块链等技术改善可再生能源市场环境，先进材料等技术改造太阳能电池板和风力涡轮机的材料。这些技术进一步助力降低成本，提高并网率，有力证明了前述两大趋势。

自动化大幅度削减了太阳能电和风电的生产和运营时间及成本。First Solar去年实现美国制造厂自动化，将发电从一个持续多日的百步流程转型为仅采取少数步骤和较少小时数，太阳能电池板产量增长两倍，而成本却是低于竞争对手30%[58]。自动化对海上风电运营产生重大影响，每GW装机容量中，海上风电的计划性维护停运次数多于其他发电技术[59]。7月，全球最大的海上风场部署全自动化无人机，将风场检查时间由两小时缩短至20分钟[60]。未来，目前处于研发阶段的爬行机器人将对太阳能电池板和风力涡轮机内部结构和材料进行自动化微波和超声波检查[61]。

通过自动化流程搜集海量珍贵数据，供人工智能协助分析，用作预测和说明。

人工智能更精准预报天气，优化可再生能源使用。由于天气情况严重影响风能和太阳能资源的可用性以及拉动电力需求的消费者行为，因此，天气预报是可再生资源并网的关键所在。寒冷刮风的天气，风电供需均会上升，而在刮风的夜晚，供应会增加，但需求保持不变。人工智能系统能够处理卫星图像、气象站测量情况、过往模式以及风力涡轮机和太阳能电池板感应器的详尽数据，预测天气情况，对比预测和实况，并利用机器学习调整自身模式，生成准确度更高的预报信息[62]。人工智能系统每天还能处理100TB以上的数据，每15分钟提供分辨率达到几百米的预测[63]。太阳能和风能领先的市场中，国家预测系统已经借助人工智能大幅提升准确度，协助运营商节约巨额资金[64]。西班牙国家风电预测系统人工智能型Sipreolico在七年的运营中，将24小时预测的失误率降低了一半。利用这一技术，超本地化人工智能预测模式目前可于一周内在几乎所有地区开展实施[65]。此外，IBM目前与美国国家大气研究中心展开合作，联合建立首个全球天气预测模型，致力于将人工智能能力推广至服务水平不足的市场[66]。

区块链是造福低水平市场的另一技术。

推行能源属性证书亟需区块链技术的支持。区块链可普遍应用于电力领域[67]。最明确的用例包括能源属性证书市场——美国主要为可再生能源证书和欧洲的来源保证。可再生能源证书概念较为简单，即各可再生能源信用证代表1MWh可买卖的可再生能源发电量[68]。然而，其跟踪流程涉及多方之间发生的复杂、代价昂贵且耗时的相互影响，并存在欺诈风险。通过共享可靠的所有交易总表，区块链消除了注册提供商、经纪人和第三方验证的需求[69]。对于多小型公司而言，这一自动化流程更透明、更便宜、速度更快且更易获取[70]。正如《德勤洞察》“区块链重塑新兴市场电网（Powered by blockchain: reimagining emerging market electric grids）”一文中所述，区块链能源属性证书还有助于破除信任和制度性障碍，这些问题在新兴市场尤为严重，并且一直努力在能源属性证书市场取得进展[71]。初创公司和成熟企业纷纷开始探索能源属性证书区块链。近期一家电力公司和证交所达成合作，共同进行概念验证[72]。

Manufacturers are heavily investing in these new technologies because they anticipate growing demand for solar and wind power.

与此同时，两大经过验证的概念为先进材料和先进制造领域的重大变革奠定了坚实基础。

先进材料和先进制造：钙钛矿和3D打印已准备就绪，即将掀起太阳能和风能产业重大变革。钙钛矿今年将逐步实现效率提升。6月，一家英德初创公司研制出硅基钙钛矿太阳电池，其27.3%的转换效率创历史纪录，优于实验环境中达最高效率的单晶硅电池[73]。7月，比利时研究人员实现类似转换效率，双方均声称有可能实现转换效率高于30%[74]。自问世以来，钙钛矿是发展速度最快的太阳能技术，在不到十年的时间里就取得了硅半个多世纪才实现的效率提升幅度[75]。相较于硅，钙钛矿拥有更为简单的化学组成，更大的光谱以及更高的理论最高效率[76]。钙钛矿还能喷涂至物质表面并印至卷形物体上，推动生产成本下降并扩大应用范围[77]。钙钛矿模块最早能在2019年实现商业化[78]。

风能方面，增材制造正在为新材料的运用奠定基础。美国两家国家实验室与行业合作生产首台3D打印风力叶片模具，大幅削减原型开发成本，并将开发时间从一年以上缩短至三个月[79]。下一个前沿领域将是3D打印叶片。这将推动利用新的材料组合和嵌入式感应器优化叶片成本和性能以及现场生产，以降低物流成本和风险[80]。生产商计划开始在风场按需进行零配件的3D打印，减少成本和维修停机时间[81]。通用电气已经运用增材制造维修并改进风力机叶片[82]。

生产商预计太阳能和风力发电需求将不断上升，因此对这些新技术投入重金。

需求

城市、社区、新兴市场和企业正在寻求低价、清洁、可靠的能源，因此，助推可再生能源需求不断上升。在这些趋势的推动下，太阳能和风能最适合满足这三方要求。可再生智慧城市认为可再生能源是其智慧城市战略中必不可少的组成部分；社区可再生能源让消费者按照自身偏好实现电气化或获取电力资源；新兴市场把太阳能和风能作为其发展战略的最佳支持方式；企业获取可再生能源，开展绿色经营并提高利润。

可再生智慧城市

可再生智慧城市认为，太阳能和风能可以推动实现他们的智慧城市目标。目前，随着城市的不断扩张，城市居民占据世界主导。其中有些城市已经踏上“智慧”之旅，借助联网传感技术与数据分析进行基础设施管理[83]。正如《德勤洞察》“变革驱动因素：智慧城市 (Forces of change: smart cities) ”所述，领先智慧城市的核心要务是改善生活质量，提升城市竞争力与可持续性[84]。太阳能和风能是实现上述目标的根本基石，不仅可有效防止污染、实现无碳发展，提升城市恢复力，还可推动清洁电动出行、赋能经济增长，同时推动业务扩张。可再生智慧城市可充分利用这一综合效应。规模最大的可再生智慧城市正在改建现有基础设施，而最新的可再生智慧城市则从零开始建设。

拥有百万人口的最大可再生智慧城市。可再生智慧城市是指拥有太阳能和/或风能，以及智慧城市计划包含可再生能源内容的城市[85]。我们的最大可再生智慧城市列表 (表1) 按城市风能和太阳能所占发电比例对百万人口以上的城市进行排名[86]。圣迭戈位居全球首位。其太阳能和风能在电力结构的占比超过三分之一，并计划在2035年达到100%的可再生能源占比。圣迭戈还是本地主导的可再生智慧城市。尽管美国终止履行气候承诺，但圣迭戈立志于通过部署可再生能源继续保持其在这一方面的领导地位[87]。相较于加利福尼亚州的全州目标，圣迭戈的可再生能源目标更为宏大[88]。作为亚洲领先城市，斋蒲尔是一个由国家层面主导的可再生智慧城市。印度中央政府制定了包含太阳能要求的“百座智慧城市”目标[89]。斋浦尔自身并未制定可再生能源目标，但今年将受益于州和国家制定的远大目标[90]。斋浦尔的主要可再生智慧城市计划是屋顶太阳能支持基础设施电力，首批建立八个日间全由太阳能提供电力的地铁站[91]。最后，欧洲领先城市汉堡是一个本地和欧盟主导的可再生智慧城市。由于未制定国家战略或支持资金筹集，德国被认为是较为落后的欧洲智慧城市，而欧盟为可再生智慧城市提供多个支持平台和筹资

表 1

前十大可再生智慧城市(57 这个数字是之前英文中的，在中文翻译中没有，在这里应该怎么写？)

城市	人口 (百万)	太阳能和风能占比等指标
圣迭戈	1.4	33%
洛杉矶	1	20%
斋蒲尔	3	20%
汉堡	1.8	14.8%
多伦多	2.8	12%
班加罗尔	11	10%
圣地亚哥	7.3	9%
首尔	10.3	6.6%
台湾	1.9	5.1%
巴黎	2.3	4.2%

来源: 德勤分析。

渠道[92]。汉堡加以充分利用，开展可再生能源部署，并将城市定位成可再生能源研究和公司的欧洲中心[93]。这些可再生智慧城市互相分享现有基础设施和系统转型为更智慧、更多可再生能源的城市过程中出现的种种问题。

新建可再生智慧城市可从零开始打造。

最新打造的可再生智慧城市。不受传统开发、既得利益和繁琐制度的阻碍，新建可再生智慧城市能够快速建立模范城市，展现并测试最新技术。Pena Station Next是一座航空城，旨在充分利用丹佛市区及其不断扩建的机场之间的火车站战略位置，这是该项目中的两大利益相关方[94]。这个面积达382英亩的社区主要依靠Xcel Energy所有、松下运行的孤岛型屋顶太阳能储能微网提供电力，Xcel Energy和松下是该智慧城市发展的另外两大主要合作伙伴[95]。国家可再生能源实验室也与丹佛市合作，协助制定净零能耗及碳平衡的社区计划。加拿大的Quayside是多伦多前十大可再生智慧城市中的新建可再生智慧城市。Quayside与Alphabet旗下的Sidewalk Labs合作开发800英亩的滨海社区，依靠屋顶和墙式太阳能供电[96]。最后，去年沙特王储宣布计划投资5,000亿美元，在红海沿岸新建面积达10,000英亩的可再生智慧城市，名为NEOM，目标是建成比拟迪拜的国际中心[97]。按照计划，这座新城将全部由太阳能和风能储能提供电力运行，并建造一座连接埃及的跨海大桥[98]。第一代新建智慧城市过度关注技术而非居民，可能成为废城而饱受批评，但这些全新的可再生智慧城市致力于融入现有城市结构，把Pena Station建成丹佛市的“生活实验室”，Quayside建成多伦多的“可持续发展模范社区”，NEOM成为亚洲和非洲的“互联中心”，太阳能和风能是其计划中不可或缺的部分。尽管Pena Station和Quayside是规模较小的可再生智慧城市，但他们能够进行技术和商业模式的概念验证，随后可在大城市中规模化发展。NEOM可在更大范围内采取同样的措施。新建可再生智慧城市的发挥空间较为自由，而面临的问题则是缩小方案选择范围，选择其中值得探索的组合方案。

新投资打造的可再生能源项目也是未连电网领域的发展关键。

V. 离网和并网社区能源

“社区太阳能”趋势已经扩大为“社区能源”并包括更为灵活的储能和管理系统。这一趋势扩大化催生了社区能源服务离网和并网地区的新方式。离网地区目前能够提供与其他能源方案价格及性能持平的电力。并网地区能够独立于电网为社区提供电力，实现了城市恢复力和供电自主权的目标。在两种情况下，随着社区能源能够普惠可再生能源部署带来的福利，众多国家均已接受社区能源。

社区可再生能源可促使离网地区实现最优电气化。离网地区的社区能源是指实现社区电气化和利润再投资的社区合作关系。这类项目大多数是由人口密度较大的农村地区的太阳能储能微网构成[99]。相较于燃料供电微网、电网扩建、燃油灯或柴油发电机，成本效益是推动太阳能供电微网发展的主要因素。可再生能源微网往往比发展中国家的电网更可靠。非政府组织已开始发起这些社区能源项目，并提供资金支持[100]。相较于其他电气化模式，社区能源的优势在于社区强有力的支持和赋能。发达国家的许多小岛市场和偏远地区亦是如此。另一方面，发达国家的部分社区利用社区可再生能源实现离网。澳大利亚尤为突出，其社区能源在2017年实现强劲增长[101]。澳大利亚国家电网以煤为主，价格昂贵且可靠性低，因此，Tyalgum等社区开展能源项目，研发自给自足的可再生能源微网，还可将多余电力售予国家电网，但又完全独立于国家电网[102]。

电网较为发达的地区，社区能源提供风能和太阳能资源的共有权和获取渠道。能源合作社目前是最常见的架构，涉及可再生能源全民共享权，共同拥有方式结合民主化运营。德国是全球能源合作社发展领先的国家：德国去年安装的可再生能源装置中，超过五分之二属于合作共有，并且德国近期实施新规为能源合作社参与电力竞价拍卖创造公平竞争环境[103]。丹麦也对能源合作社提供大力支持，要求所有风能项目必须包含20%的本地社区份额[104]。能源合作社大幅度提升居民参与度，为这两个国家的可再生能源部署提供有力支撑。在国家竞争的刺激下，丹麦萨姆

索岛十年内成功从完全依赖化石燃料的市场转型为采用社区能源模式、100%依靠可再生能源的岛屿[105]。如德勤发表的"全面释放社区太阳能的价值(Unlocking the value of community solar)"所述，能源合作社也处于美国社区能源的发展前沿[106]。受会员客户需求的推动，合作共有的公用设施占据了70%以上的社区太阳能项目[107]。近一半美国家庭和企业无法拥有太阳能系统，社区能源让他们能从共享太阳能项目中购电并建立公共设施账单的信用记录[108]。第三方提供商将三分之二的社区太阳能电量主要分配给商业客户，其中大多数客户位于科罗拉多州、明尼苏达州和马萨诸塞州，其余电量主供公共设施和居民用户[109]。在低成本、可再生能源客户需求和城市恢复力的推动下，社区能源需求愈加旺盛。后者在马萨诸塞州的社区清洁能源恢复能力计划 (Community Clean Energy Resilience Initiative) 补助项目中得到充分反映，该项目旨在保护社区免遭电力服务中断故障[110]。许多经历过天灾或恶劣天气现象后断电的社区逐步转向社区可再生能源微网，利用这一电力恢复手段保护关键基础设施。日本情况相同，也制定国家层面的电力恢复计划以支持社区能源[111]。

While cities and communities are increasingly relevant actors in the deployment of solar and wind power in developed markets, the national level is most relevant in emerging markets.

太阳能和风能发达市场部署中，城市和社区日益成为重要的参与方，而许多新兴市场最重要的参与方却是国家。

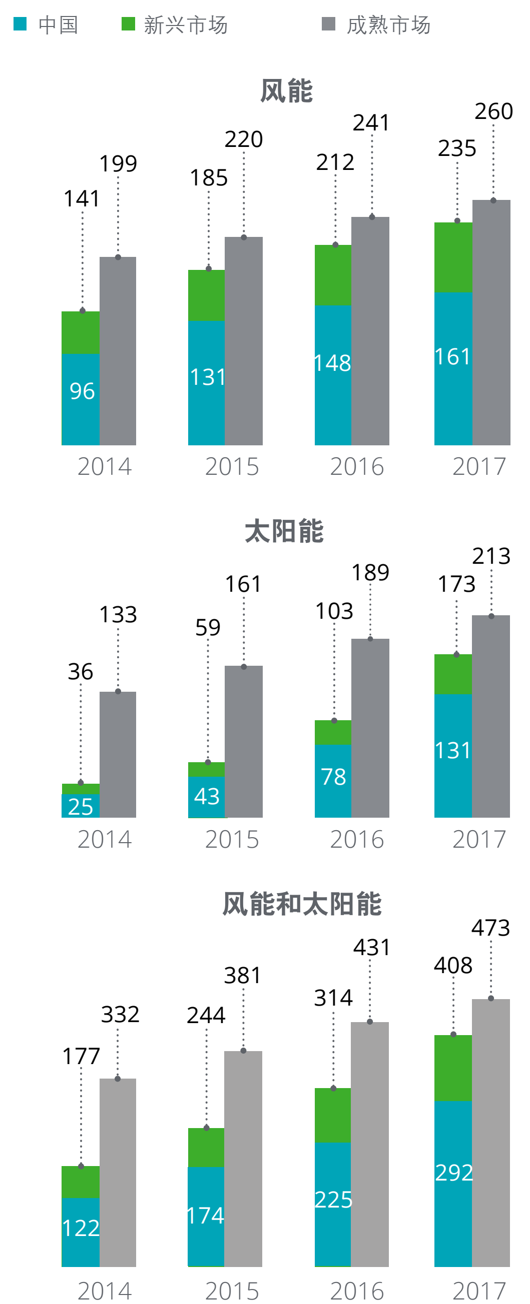
VI. 新兴市场领先一步

发达国家（33个高收入经合组织成员国）的太阳能和风能产业及市场已经启动并日趋成熟，但重心近期转向新兴市场（所有非发达国家）[112]。2013年，新兴市场的陆上风电增长率超越发达国家；2016年，太阳能光伏增长率实现超越；2017年，新兴市场占全球可再生能源新投资的63%，推动其与发达国家之间的投资差距创历史新高[113]。目前，新兴市场的累计装机发电容量即将超过发达国家（见图5）。新兴市场助推可再生能源成本降低，并在可再生能源部署方面赶超发达国家，追求低碳经济发展，并实现创新，同时造福全球环境。

作为全球领先国家，中国不断推动新兴市场的可再生能源增长。2017年，中国太阳能和风能增长及总装机发电容量全球第一并创下历史新纪录，是唯一一个两种资源均高于100GW的市场。2017年，仅中国就占据了超过一半的新增太阳能装机发电容量，占全球光伏产量的三分之二。前十家太阳能光伏供应商中有八家为中国企业，前三家中国风能企业总共占据最大的风能市场份额[114]。中国还是唯一一个同时进入前十位新兴市场跨境清洁能源投资地和前十大投资者的国家，也是唯一进入十大投资者排名的新兴市场。从2015年创下跨境清洁能源投资记录到2017年上半年，中国在另外11个新兴市场的风能和太阳能投资额达22.3亿美元，吸收了来自13个国家的13.4亿美元风能和太阳能投资[115]。

图 5

发达国家和发展中国家风能和太阳能的增长率和累计装机发电容量



Note: All numbers are in thousand MW.
Source: Capacities calculated from IRENA, *Renewable capacity statistics 2018*.

即使不计中国，新兴市场仍在推动可再生能源增长并具有最大的未来增长潜力。新兴市场的太阳能和风能装机发电容量竞价拍卖打破了最近的记录。2017年，墨西哥和阿联酋分别创下全球风能和太阳能最低出价拍卖记录。印度凭借竞价拍卖不断扩大市场，吸引积极进取的新企业，成为全球最具竞争力的可再生能源市场[116]。印度和土耳其2017年的太阳能装机发电容量翻了一番，印度近期更是将其目标提升为可再生能源2022年达到227GW[117]。过去两年中，所有新增聚光太阳能热装机发电容量全部来自新兴市场。南非是2017年唯一一个有新增聚光太阳能热上线运行的国家，而阿联酋宣称开展全球最大的聚光太阳能热项目，预计将于2020年投入运营。可再生能源投资在国内生产总值占比最高的国家全为新兴市场，包括马绍尔群岛、卢旺达、所罗门群岛、几内亚和塞尔维亚[118]。最后，撒哈拉以南非洲是最大的电气化未开发市场，意味着可再生能源蕴含巨大增长机遇。针对低密度地区中最边缘化且未通电的人群，现付现用的太阳能家庭系统通常是最适合的电气化方案。根据国际能源署预计，未来二十年，未使用电力的大多数人将通过分散化的太阳能光伏系统和微网实现通电[119]。

即使不计中国，新兴市场仍在推动可再生能源增长并具有最大的未来增长潜力。

新兴市场大力培养创新能力。发达国家得益于来自新兴市场的市场和产品设计。举例而言，可再生能源竞价拍卖首创于新兴市场，随后促使全球可再生能源高企的价格大幅下降[120]。新兴市场设计的部分太阳能和风能产品通过逆向创新而应用于发达国家。例如，专用于发展中国家离网地区供电的微网也运用于发达国家的偏远矿区[121]。

从更全面的角度来看，企业发挥着越来越重要的作用，协助推动发达国家和发展中国家的电力转移，促进可再生能源不断发展。

VII. 企业参与范围日益扩大

越来越多行业领域的企业纷纷尝试以新的方式采购可再生能源。额外性作为黄金标准，是指确保采购能够创造可衡量的额外可再生能源装机发电量，因此企业愈加关注采购质量，而购电协议则成为他们的首选途径。购电协议可以提供最大限度的额外性，但主要是大型企业采用。小型企业则采取集群化发展。随着大型企业将供应链纳入其可再生能源相关目标中，他们也在在协助小型企业采购可再生能源。

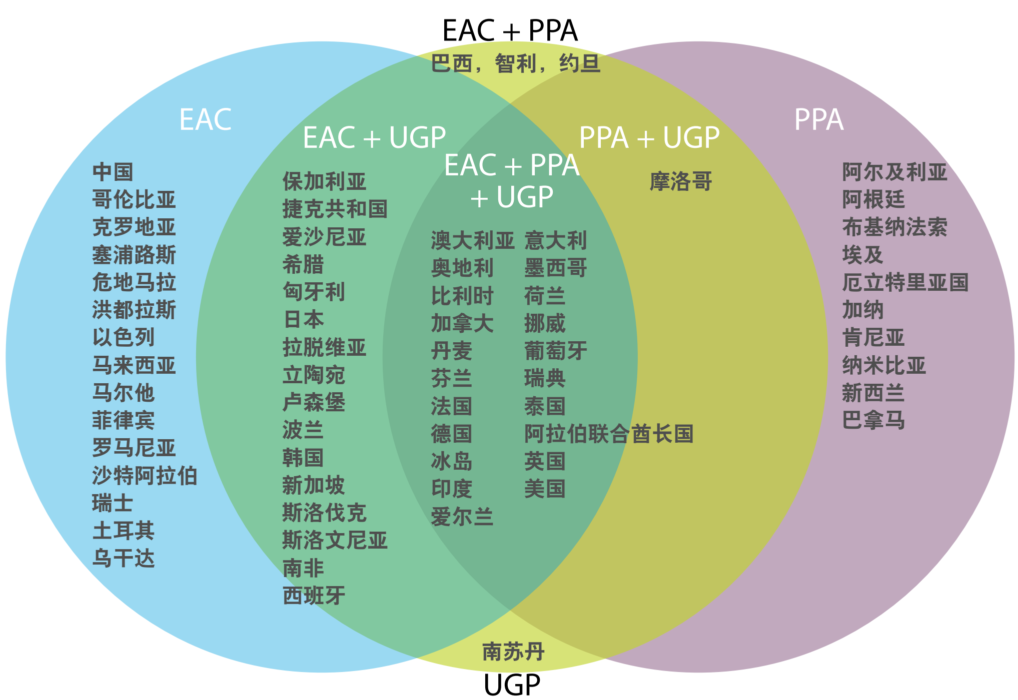
购电协议是发展速度最快的企业采购途径。2017年，全球企业通过自行发电或采购共获得465TWh可再生能源电量。75个国家的企业不同程度上利用三大途径获得可再生能源：能源属性证书、购电协议和绿色公共采购计划。能源属性证书是最常广泛使用的采购途径，在57个国家可轻松获得。公司利用这一途径证明其符合政府的可再生能源要求或自愿性目标。然而，公司却不能充分获取可再生能源的成本效益且证书的额外性未必可靠。39个国家准许进行绿色公共采购计划，大多为欧洲国家，但其使用率和透明度最低。该类计划通常与能源属性证书相关，具有相同短板。购电协议在35个国家可实施且正在快速

扩展。2017年，有10个国家的企业签署了5.4GW的可再生能源购电协议，创历史新高[122]。相较于能源属性证书和绿色公共采购，购电协议的额外性更高且节约更多成本，并且低于常规电力成本。尽管如此，小型企业却难以获取。电力成本超过营运费用15%的企业会首选购电协议[123]。其中大多数企业积极管理能源采购这一大笔支出。北美洲和大多数欧洲国家均可采用这三大途径。这些发达国家仍将引领企业采购市场，技术行业继续保持领先。然而，其他领域的企业也在加大可再生能源采购，新兴市场更容易开展可再生能源采购。巴西、印度和墨西哥等新兴市场也提供全方位服务，且跨国和国内企业采购不断增多。

通过集群化发展和供应链实现企业综合效应。目前已有三分之二的财富全球100强企业设立了可再生能源目标，凭借购电协议成为全球企业采购的主力军，其中许多企业已经加入RE100倡议。该倡议目前共有140家成员公司（截至2018年8月）承诺其全部电力均来自可再生能源， 其中25家公司在2017年实现目标。尽管这些部署活动均有积极意义，但只有众多小型企业参与其中并能够获取全方位的企业采购服务，可再生能源企

图 6

文氏图展示75个国家的三大途径



Source: IRENA, “Corporate sourcing of renewables: Market and industry trends,” 2018.

业采购趋势才能得以维持。正如德勤2017年发布的报告"严肃以待：企业采购优于可再生能源政策扶持（Serious business: corporate procurement rivals policy in driving growth of renewable energy）"所述，中小企业代表着新一轮机遇[124]。通过集群化发展，小型企业能够达成合作关系共同执行公用事业规模的购电协议。部分项目开发公司目前作出让步，与小型公司聚合一系列购电协议。去年，一家财富1000强企业就一个80MW风能项目的10%份额签署购电协议[125]。该公司将受益于该项目的规模经济，而开发公司则将获益于多样化的客户基础以及由七家小型公司组成的金融风险池。企业采购的范围通过供应链不断扩大。三分之一的RE100企业将其可再生能源目标上调100%，并囊括其供应链。范围越大，就能产生更多收益，包括为新兴市场的可再生能源带来跨国企业专业技能和资金。一家可再生能源企业采购巨头近期设立了3亿美元的清洁能源基金，在中国投资部署1GW的可再生能源项目，并希望这一模式可进行复制[126]。

结语

太阳能和风能在2017年步入新高度，成为优选的能源资源，在2018年其全球电价和性能方面已逐步与传统能源持平。太阳能和风能能够强化电网功能，并通过新技术提升竞争能力，其部署障碍和制约因素日益消解。2018年太阳能和风能成为全球最便宜的能源资源，发展趋势是将在新技术大幅提高效率和能力的支持下，成本持续下降，积极并网活动也进展迅速。与此同时，可再生能源的需求不断稳定增长。太阳能和风能即将满足三大能源消费需求：成本效益、无碳发展和可靠性。丹麦等领先可再生能源市场中，欧盟、国家和本地社区利益与这些需求紧密相关。在美国和澳大利亚等其他国家，尽管国家领导层弱化无碳发展工作，而城市、社区和企业成为最重要的参与方。他们加大力度填补空白，推动需求持续上升。最后，新兴市场不断发展和/或开展电气化，将实现跳跃式发展和最为可观的电力增长，稳居太阳能和风能领军市场的地位。可再生能源也不再需要实践案例，而传统能源却并非如此。

尾注

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