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Shenzhen Institute of Building Research Co., Ltd
深圳市建筑科学研究院股份有限公司

建筑电气化及其驱动的城市能源转型路径报告摘要

Pathways of Building Electrification and Urban Energy Transform Summary Report

深圳市建筑科学研究院股份有限公司

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执行摘要

■ 建筑节能发展进入新时期

- **低碳发展成为全球共识。**至今全球已有 170 多个国家签署《巴黎协定》，确定了未来全球温升控制在低于 2 度且尽可能争取 1.5 度的奋斗目标。中国作为碳排放大国，积极推动低碳事业的发展，主动提高国家自主贡献力度，采取更加有力的政策和措施，二氧化碳排放力争于 2030 年前达到峰值，努力争取 2060 年前实现碳中和。尤其在当下疫情致使全球经济增速放缓，经济绿色复苏备受关注。
- **可再生能源蓬勃发展。**可再生电力能源是实现化石能源替代的根本途径，大量研究表明中国可再生能源在 2050 年一次能源消费中的占比将达到 50%以上。建筑电气化是促进可再生电力能源在建筑领域运用的必要途径。
- **建筑外表资源化利用。**风能、太阳能具有能量密度低、分布分散的特点，因此分布式是风光电源发展的重要形式。建筑屋顶以及可能接受到足够多的太阳辐射的建筑垂直表面，都将成为安装太阳能光伏的最佳场景。粗略估算我国民用建筑屋顶可安装光伏的表面面积超过 100 亿平米，年发电量可达 2 万亿 kWh。用好建筑外表面，使其成为建筑用电的主要来源，将成为建筑节能的新途径。
- **城市能源系统可持续发展。**可再生电力能源的高比例渗透将对城市能源系统的安全可靠性构成严峻挑战，构建“源网荷储控”一体化模式和“热电气”多能协同模式是应对这一挑战、实现城市能源系统可持续发展的关键。挖掘建筑分布式蓄能和可调节负荷，提高建筑能源的灵活性正在逐渐成为建筑节能除能效提升外的新维度。
- **农村和西部地区经济振兴。**农村和西部地区有丰富的土地资源，是发展太阳能、风能、生物质能等多种可再生能源的基础。生活热水、采暖、农用器械等的电气化可以提高能源利用效率、减少散煤使用，对改善农民生活水平、减少环境污染、推动农村经济建设有重要意义。

■ 中国建筑电气化处于快速发展阶段

- **中国建筑电气化进程持续快速发展。**截至 2017 年，建筑用电量占全社会用电量的 26%，人均建筑用电量达 1186kWh，建筑电气化率 48%。对比 2001 的指标，人均建筑用电量增长了 4 倍，建筑电气化率提高了 29%。
- **中国各省市的电气化进程差异明显。**建筑人均用电量与各地居民的消费水平强相关，北京、上海等一线城市的建筑人均用电量接近 3000kWh，是

全国平均水平的 2 倍有多。另外，由于南北供暖需求的差异，建筑电气化率的南北差异较为明显。

- **中国建筑人均用电量距发达国家有明显差距。**中国的建筑人均用电量距离欧美发达国家还有一定差距，中国的建筑电气化还有很大的增长潜力。但是这并不意味着中国未来的建筑人均用电量就不一就会增长到欧美国家的水平，还应考虑到用能模式的差异和能效水平的提升。

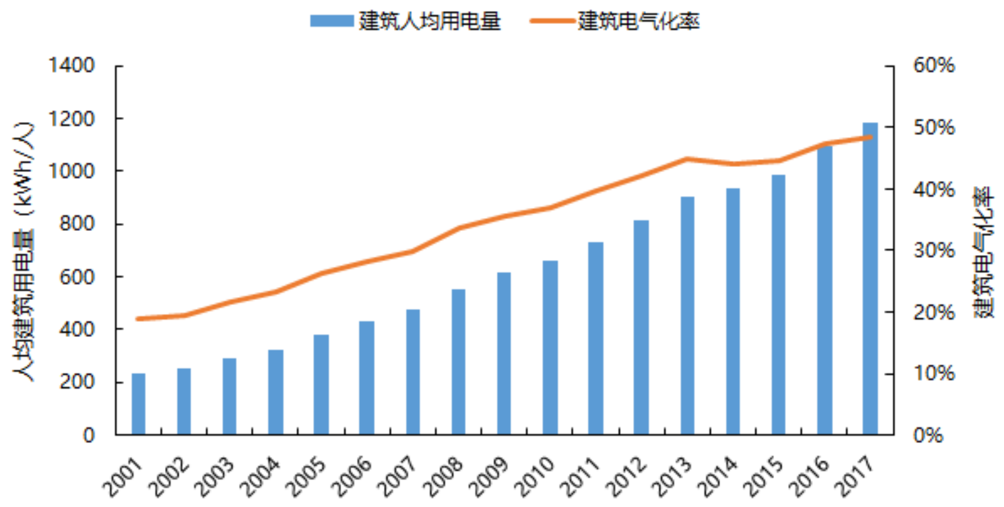

图 i 中国建筑人均用电量和建筑电气化率

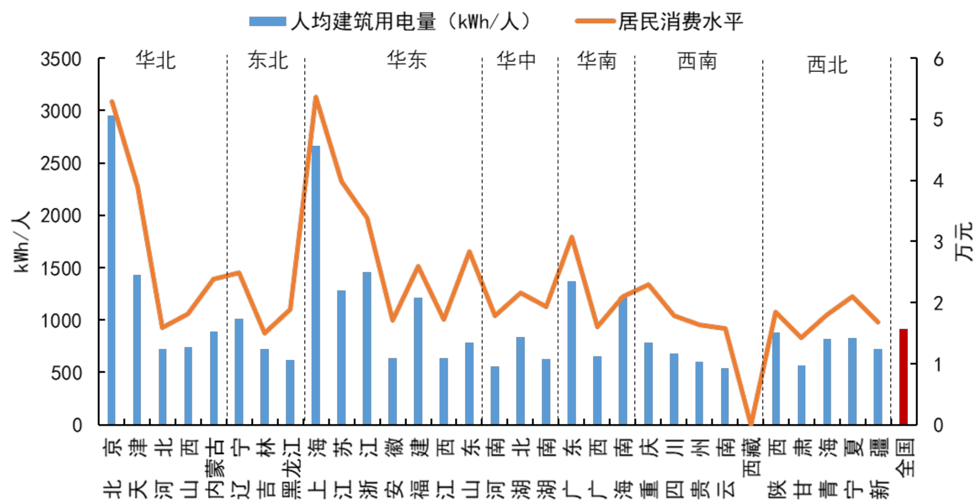

图 ii 分省市建筑人均用电量和居民消费水平

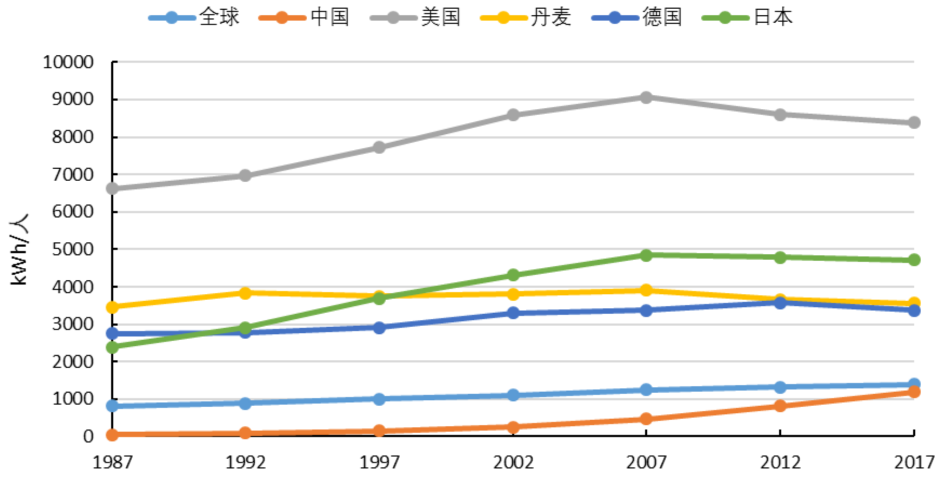

图 III 中国与发达国家的建筑人均用电量

■ 建筑电气化政策风靡全球

- **加州推进建筑电气化致力于实现 2045 年碳中和的目标。**2019 年伯克利率先立法禁止新建建筑中使用天然气，随后除伯克利外美国加州超过 25 个城镇采取措施要求或大力支持新建建筑的电气化，另有 50 余个城镇正在考虑制定类似的法规措施，推进建筑电气化。洛杉矶 2019 可持续发展计划要求 2030 年在洛杉矶实现新建建筑零排放，到 2050 年完成所有已有建筑的零排放改造；圣何塞目标在 2030 年实现 47%的建筑电气化。

- **欧洲供暖电气化以实现供热和制冷领域减碳 86%等目标。**2018 年欧洲学者制定了第 4 版欧洲供热路线图（Heat Roadmap Europe 4），在未来城镇集中供热区域，大型热泵在集中供热总热量中的占比将达到 25;，在集中供热管网不可及的地区，高效热泵将提供分散供暖区域的热量的近 50%。相比于 1990 年的水平，2050 年的供热和制冷领域的碳排放量将降低 434 万吨或 86%；相比于常规减碳模式，新的减碳技术路线可以减少每年 6%的投资成本；相比于 2015 年，2050 年的供热和制冷领域的化石能源消耗量降低 10.4TWh。同时，天然气和低效电供暖技术完全替代，供热和制冷领域的技术能够支撑整个能源系统实现 100%可再生能源。

■ 需求侧：建筑用电量和建筑电气化率提升

- **用电量的自然增长。**建筑用电量与居民消费水平强相关，因此随着人们生活水平的提高，电器数量加使用强度均会自然增长。如果未来全国平均用电量水平向目前一线城市看齐，建筑人均用电量约 2800kWh，那么全国建筑用电量将超过 4 万亿 kWh。与此同时，建筑节能政策的延续会持续降低建筑供暖能耗强度，几乎抵消北方地区建筑供暖面积增加导致的能耗增长。此消彼长，建筑电气化率也会自然增长。

- **生活热水电能替代。**对于居住建筑和公建建筑的集中式生活热水系统，

由于存在热损失大的问题，采用分散式电热水器能够有效实现节能，并且促进可再生能源的利用；对于公共建筑的生活热水系统，将其从蒸汽供热系统中独立出来，采用高效电热泵作为替代热源，具有显著的节能效益。

- **北方城镇供暖电能替代。**北方城镇集中供热管网普及，是充分利用城市内部或周边的热电联产和工业余热的基础。这些热源比电热泵等电供暖电气化技术更加高效和经济，应该作为城镇集中供暖的优选热源。再考虑到冬季光电、水电等可再生能源量减少的问题，供暖电气化技术主要用于补充供热缺口，可以在城镇集中供热中占据一定比例，但不应过分追求完全电气化。

- **北方农村供暖电能替代。**北方农村推广空气源热泵等采暖电气化技术是替代散煤、减少大气污染物排放的有效途径。然而，单纯“煤改电”而不增强建筑保温性能会导致农户用电成本增加和农村配电网增容承压。从提高室内舒适度、降低农户的采暖成本、保障电力安全等角度出发，农村采暖电气化应该与建筑围护结构保温、建筑需求响应技术共同实施。

- **炊事电能替代。**一方面随着城镇居民越来越多地选择在外用餐，炊事能耗从住宅向公建转移，因此需要更多关注公建炊事电气化；另一方面，居民用户的炊事习惯改变是住宅炊事电气化的难点，需要加以引导，同时推广高效电炊具，通过效率差解决价格差。

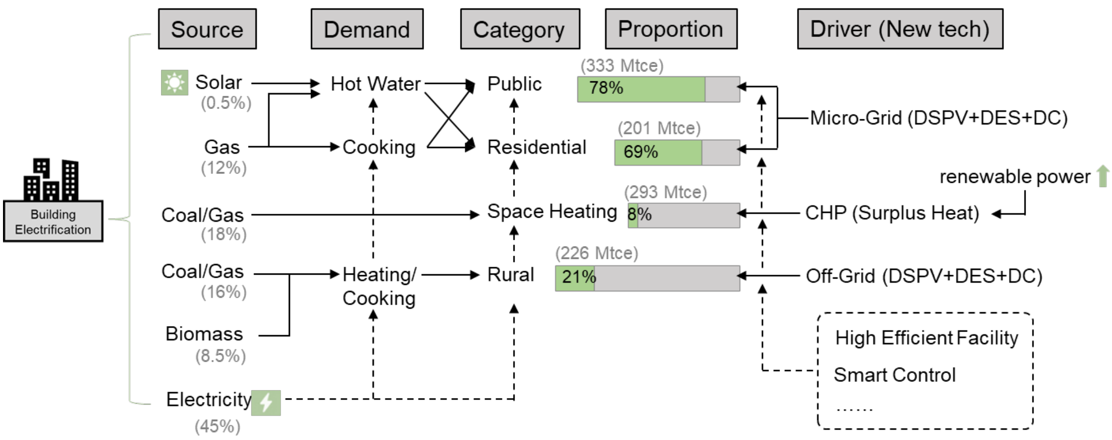

图 IV 建筑电气化率提升技术途径

■ 供给侧：“光、储、直、柔”建筑新型供配电技术

- **建筑新型供配电技术的特征。**“光”指的是在建筑场地内设置的分布式光伏发电装置，“储”在供配电系统中主要是储能电池，“柔”则是具有可调节、可中断特性的智能建筑用电设备，包括智能空调、智能照明、智能充电桩等智能化设备，“直”是指低压直流配电系统。

- **建筑新型供配电技术的特征的优势。**“光、储、直、柔”建筑新型供配电系统与建筑传统供配电系统相比具有显著的差别，一方面是源、储、荷

的布局从分离到融合；另一方面终端建筑的用电需求也将从原来的刚性需求（用户用多少、电网供多少）转变为柔性需求（可中断、可调节）。另外，低压直流配电技术的应用使建筑供配电系统简单化，促进能效提升、可靠性提高和能量智能化控制的发展。

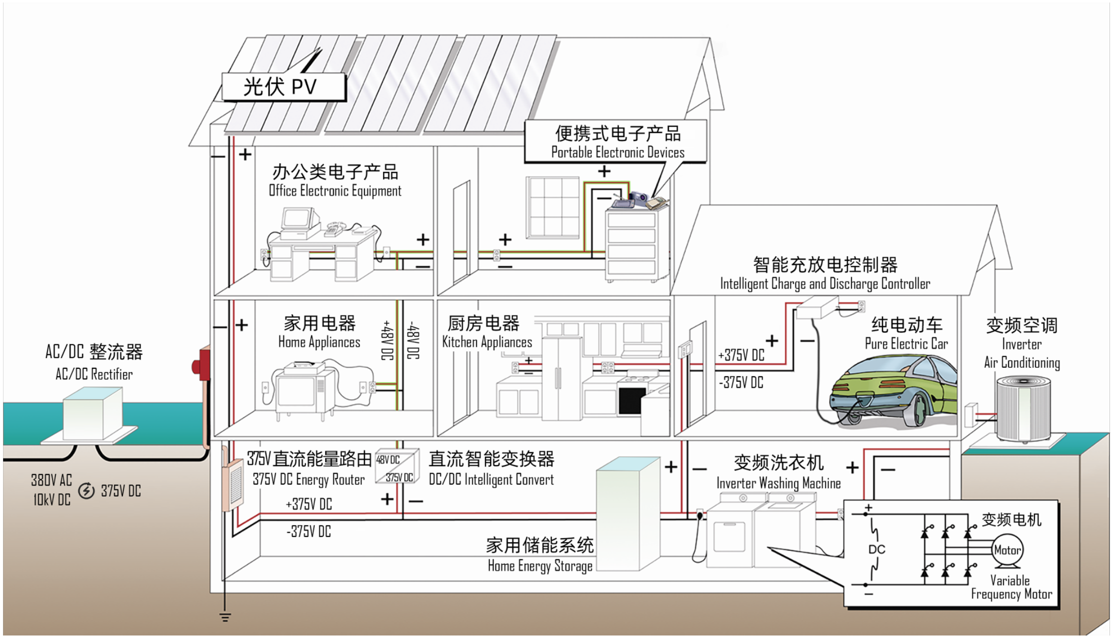

图 V“光储柔直”建筑新型供配电技术

■ 建筑电气化促进低碳发展和产业升级

- **2050 年建筑电气化率超过 90%，才有可能实现碳中和或 1.5 度目标。**基于 LBNL 的建筑用能模型，本项目建立了建筑电气化情景。在建筑用能需求合理增长的前提下，建筑电力系统至少达到双 90%（即建筑电气化率 90%，建筑电力供给中非化石比例 90%），同时大力推进建筑节能工作，建筑碳排放量才有可能降到 5.5 亿吨左右，基本满足巴黎协定 2 度目标的要求。而要想实现碳中和或 1.5 度的目标，则必须实行更激进的建筑电气化和建筑能耗总量控制政策。

- **2030 年建筑碳排放达峰。**在电气化情景下，建筑碳排放量预计在 2030 年达到高峰，建筑碳排放峰值为 21 亿吨二氧化碳。

- **大气污染物有效控制。**在电气化情景下，2050 年 NOx 和 SO_2 排放量相比 2020 年分别减少了 82%和 83%，相比基准情景分别减少了 75%和 77%。

- **促进建筑供配电产业升级。**“光储柔直”新型建筑电力系统发展将带动其核心技术包括分布式光伏、分布式蓄电、建筑直流配电、柔性建筑能量管理、能源互联网等技术的发展。根据直流建筑联盟的测算，关联产业链的市场规模高达 7000 亿每年。

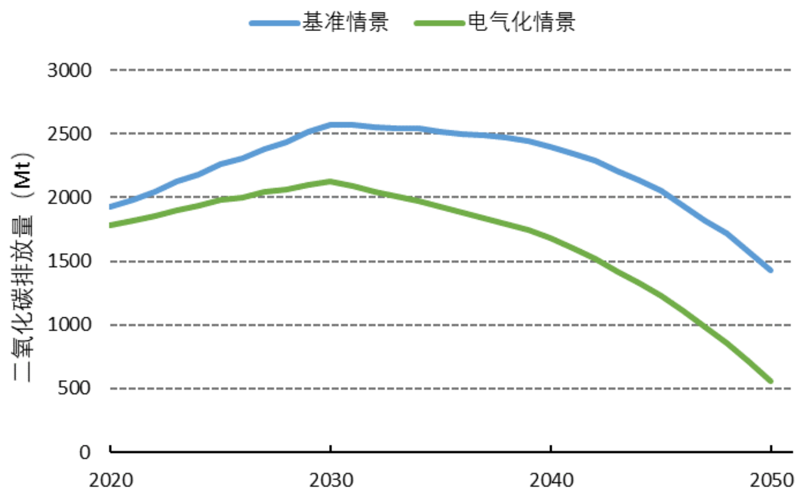

图 VI 建筑碳排放量预测（含终端直接碳排放和电力间接碳排放）

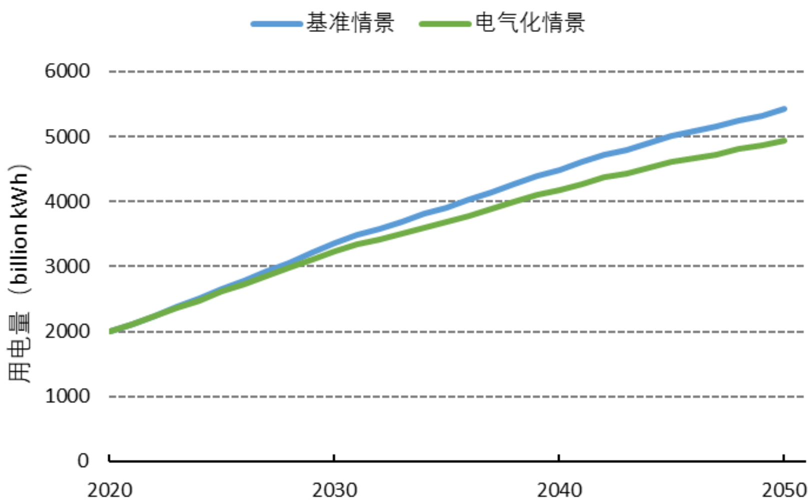

图 VII 建筑用电量预测

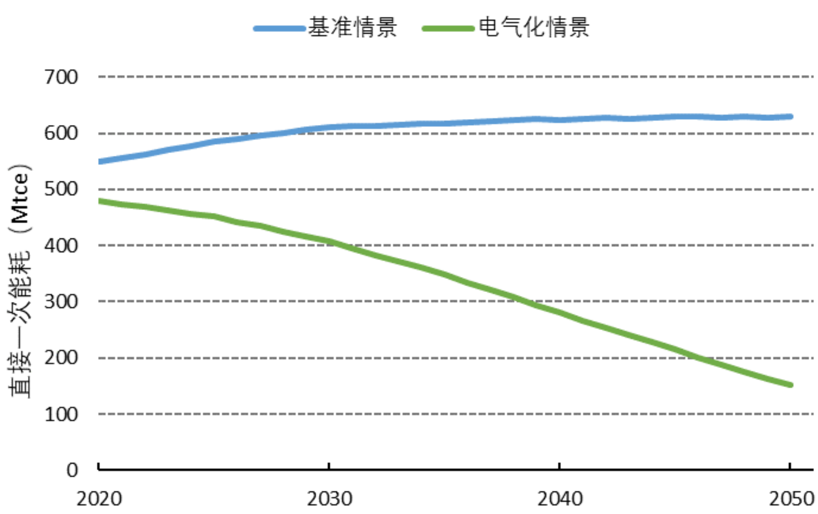

图 VIII 建筑直接一次能耗量

■ 建筑电气化的发展目标

图 Ⅸ 建筑电气化的发展目标

		2018	2025	2035	2050
电力供给指标	城市分布式光伏覆盖率	0.5%	1.4%	2.7%	3.0%
	建筑非化石电力供给比例	29%	40%	55%	90%
	建筑供电可靠率	99.94%	99+X%		
电力消费指标	人均建筑用电量（kWh）	1180	2000	2600	3400
	建筑电气化率	48%	60%	75%	90%
	建筑用电量占全社会用电量比重	26%	30%	35%	40%
项目建设指标	建筑光伏装机容量（GW）	20	80	300	1000
	建筑储能配置容量（GWh）	/	0.5	25	300
	“光储柔直”建筑面积（亿平米）	/	0.5	20	200

- **近期：2020-2025 年建筑用电量迅速增长、“光储柔直”技术起步。**十四五期间随着经济水平提高和电能替代工作在清洁供暖、生活热水等领域的持续推进，人均建筑用电量将维持略高于十三五期间的年均增速，预计到 2025 年人均建筑用电量将达到 2000kWh，建筑电气化率达到 60%（按照发电煤耗法计算）。城市分布式光伏覆盖率达到 1.4%，建筑非化石电力供给比例达到 40%，建筑供电可靠性实现“电网提供 99%，建筑自行解决额外 0.X%的可靠性需求”。与此同时，建筑储能和“光储柔直”集成化技术尚处于初期发展阶段，主要依赖于国家制定政策推动示范工程落地，预计到 2025 年采用“光储柔直”集成化技术的建筑面积达到 5000 万平米，建筑光伏（不含工业建筑）的累计装机容量将达到 80GW，建筑储能的应用规模达到 50 万 kWh。

- **中期：2025~2035 年建筑用电量增长放缓、“光储柔直”技术快速发展。**在 2025~2035 年期间，考虑到社会经济增长速率变缓，人均建筑用电量和电气化率的增长速率也将随之变缓，预计到 2035 年人均建筑用电量达到 2600kWh、建筑电气化率达到 75%（按发电煤耗法算）。城市分布式光伏覆盖率达到 2.7%，建筑非化石电力供给比例达到 55%。与此同时，随着建筑光伏一体化、建筑储能、“光储柔直”集成等技术的成熟和经济性凸显，同时考虑到中国政府做出的在 2030 年左右碳达峰的承诺，可再生能源技术和新型建筑供配电技术将会在 2025~2035 年期间迅速发展，预计到 2035 年建筑光伏累计装机容量达到 300GW、建筑储能累计配置容量达到 25GWh、应用“光储柔直”集成化技术的建筑面积达到 20 亿平米。

- **远期：2035~2050 年建筑领域高度电气化、“光储柔直”技术成熟、可再生能源高比例渗透。**在 2035~2050 年间，建筑用电量仍会保持稳定的速率增长，电能替代工作持续深入推进，预计到 2050 年除了北方集中采暖使用热电联产和农村使用生物质外，其他建筑用能需求基本上实现电气化，人均建筑用电量达 3400kWh，建筑电气化率达到 90%（发电煤耗法）。城市分布式光伏覆盖率达到 3.0%，建筑非化石电力供给比例达到 90%。与此同时，“光储柔直”技术大规模应用，预计到 2050 年的应用建筑面积超过 200 亿平米，建筑光伏的累计装机容量达到 1000GW，建筑储能的配置容量达到 300GWh。

■ 建筑电气化的 S. W. O. T. 策略

图 X 建筑电气化的 S.W.O.T.分析

		优势（S）	劣势（W）
外部因素 \ 内部因素		• 促进可再生能源发展 • 提高建筑能效和用能可靠性 • 实现建筑能源管理和需求响应 • 促进建筑与电网、交通、工业的协同发展	• 用户行为改变需要时间 • 关键设备研发需要前期投入 • 标准和政策还不完善
机遇（O）	• 低碳能源转型 • 源网荷储控一体化 • 新型城镇化、新农村建设、经济内循环	SO策略 **瞄准新需求，解决新问题** • **提高建筑灵活性、可靠性。**发展高效电能替代和新型建筑电力系统，提高建筑电力系统能效和可靠性，实现建筑能源管理和需求响应，促进城市低碳能源转型和源网荷储控一体化发展 • **能源供给清洁化、智能化。**在城市和农村发展新型建筑电力系统，促进新型城镇化发展、新农村建筑，依托国内产业链促进经济内循环。	WO策略 **利用既有创新政策、平台和资金** • **建立示范建筑或示范区域。**试行新技术和新政策，整合产业链，制定迭代标准，检验技术政策的可行性和用户的接受度
挑战（T）	• 天然气发展 • 经济下行压力 • 既有电价政策下的利益格局	ST策略 **推广既有成熟技术** • **借鉴其他领域的既有技术。**建筑与电网、交通、工业的协同发展，减小技术迭代周期，降低设备成本 • **推广电热泵技术。**发挥电气化的减排优势和安全优势，推动高效电能替代，尤其是农村散煤燃烧和城镇燃煤锅炉 • **推广光伏技术。**充分利用本地分布式可再生能源，降低用户用能成本，甚至在可再生能源丰富的农村为用户创收	WT策略 **争取新的创新政策、平台和资金** • **国家根据远期低碳发展目标做顶层规划，**明确建筑电气化的发展路径 • **对示范工程和创新技术给予财政补贴和政策支持，**鼓励电能替代，新型建筑电力系统的技术创新、设备研发和标准编制

- **SO 策略-瞄准新需求，解决新问题。**发展高效电能替代和新型建筑电力系统，提高建筑电力系统能效和可靠性，实现建筑能源管理和需求响应，促进城市低碳能源转型和源网荷储控一体化发展；在城市和农村发展新型建筑电力系统，促进新型城镇化发展、新农村建筑，促进能源供给清洁化、智能化，并依托国内产业链促进经济内循环。

- **WO 策略-利用既有创新政策、平台和资金。**建立示范建筑或示范区域。试行新技术和新政策，整合产业链，制定迭代标准，检验技术政策的可行性和用户的接受度。

- **ST 策略-推广既有成熟技术。**借鉴其他领域的既有技术，实现建筑与电网、交通、工业的协同发展，减小技术迭代周期，降低设备成本；推广电热泵技术，发挥电气化的减排优势和安全优势，推动高效电能替代，尤其是农村散煤燃烧和城镇燃煤锅炉；推广光伏技术，充分利用本地分

布式可再生能源，降低用户用能成本，甚至在可再生能源丰富的农村为用户创收。

- **WT 策略-争取新的创新政策、平台和资金。**国家根据远期低碳发展目标做顶层规划，明确建筑电气化的发展路径；对示范工程和创新技术给予财政补贴和政策支持，鼓励电能替代，新型建筑电力系统的技术创新、设备研发和标准编制。

■ 建筑电气化的政策建议

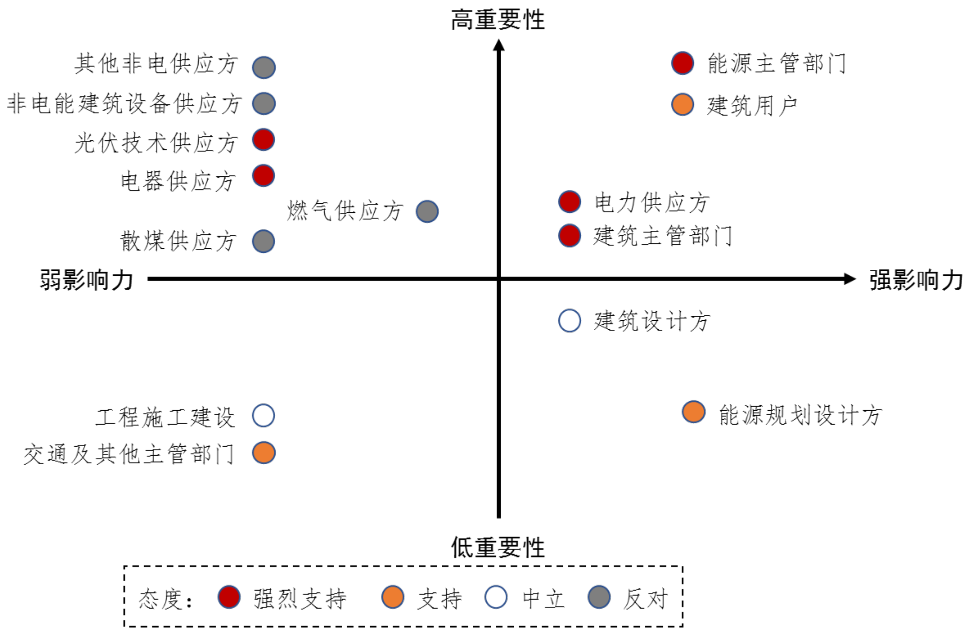

图 XI 建筑电气化的利益相关方

- **明确建筑电气化目标。**在能源、电力、可再生能源、应对气候变化、节能减排、建筑节能与绿色建筑等专项规划中予以体现。
- **完善技术标准规范。**组织编制直流建筑、电网友好型建筑、能源互联网用户侧技术等建筑电气化相关的技术标准规范。
- **加强建筑电气化技术研究。**研究分布式光伏、分布式蓄电、柔性用电负荷、建筑低压直流配电等技术的“光储直柔”建筑新型供用电系统。
- **加强建筑电气化机制研究。**研究适应分布式能源和储能发展的电价机制，建筑与电动车充电桩的协同设计运行技术、建筑与城市电网的交互技术和补偿机制。
- **推动示范工程建设。**设立新型电气化技术应用试点，规划实施高效电能替代技术和建筑新型供配电技术，试行新的政策机制。
- **扶持建筑新型供配电技术产业链发展。**在建筑直流配电、建筑储能等产业发展前期给予财政补贴支持。

- **激励建筑电气化的利益相关方。**加强宣传增强重要性高且影响力强的主体对于建筑电气化行业发展路径和目标的理解;加强引导重要性高但影响力弱的主体有序参与到建筑电气化过程。

■ 建筑电气化与电网、交通、工业协同发展

- **建筑与电网。**建筑是城市电网的消费主体，建筑电气化提升自身用电量促进电力消费增长。采用“光储柔直”供配电技术的新型建筑具有较强的电力灵活性,可以实现电力解耦和离网运行,增强电力系统的可靠性。电网满足 99%的可靠性基本需求，建筑根据自身特点自行解决额外 0.X%的可靠性需求。此外，建筑灵活性提升还能促进建筑分布式能源系统参与城市电网的调峰和调频服务，促进消纳更多可再生能源；削减建筑负荷峰值，缓解小区配电网增容压力和城市电网调峰压力。

- **建筑与交通。**随着新能源汽车逐渐从 B 端市场向 C 端市场转移，私家车全天平均停车时长高达 80%，快充的必要性逐渐降低。再考虑到电动车充电对配电变压器负荷峰值的影响，建筑周边充电桩的运行模式应以慢充为主，并且需要有序充电、双向充放电技术的支撑。未来住宅小区和公共建筑的配电网与汽车充电桩需要统筹建设，建筑用电与交通用电的耦合程度也将越来越高。

- **建筑与工业。**建筑电气化依托于光伏、储能、直流配电等建筑新型供配电技术。工业和民用建筑是城市中的两大应用场景。新型供配电技术会在不同场景中协同发展。例如低压直流配电技术在建筑场景中主要用于促进建筑光伏和储能的应用，增强建筑电力灵活性；而在工业场景中则主要用于治理电压暂降问题，保障供电可靠性。储能电池在汽车工业中主要关注能量密度和行驶安全；在建筑场景中则主要关注储能经济性和消防安全。

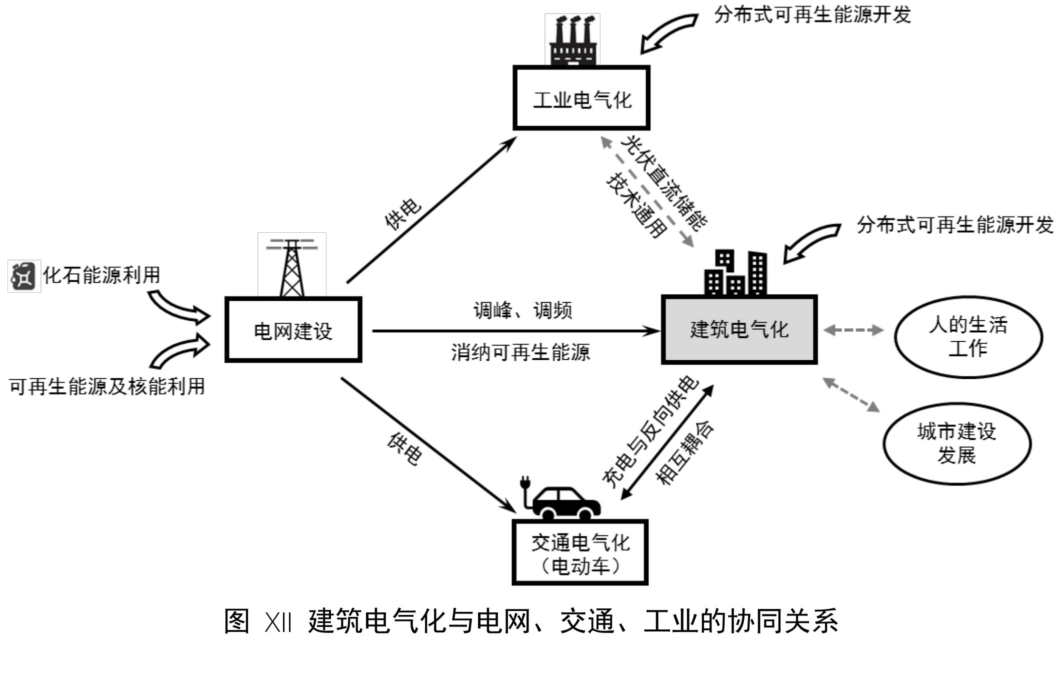

图 XII 建筑电气化与电网、交通、工业的协同关系

Executive Summary

New Era for Building Energy Saving Development

- **Global consensus on low-carbon development.** More than 170 nations in the world have signed the Paris Agreement, setting the goal of the global temperature rise to well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit the temperature rise to 1.5 degrees Celsius. As a main carbon emissions country, China actively pushes forwards lower emissions and intensifies nationally determined contribution. More powerful policies and measures shall be adopted to have carbon dioxide emission reached at its peak by 2030 and achieve carbon neutral by 2060. Especially the current pandemic leads to slowdown of global economic growth so that much attention is paid to green economic recovery.

- **Renewable energy booming.** Renewable electrical energy is the basic approach to replacing fossil energy. Massive researches show that renewable energy in China is expected to reach more than 50% in primary energy consumption by 2050. Building electrification is a necessary approach to promote application of renewable electrical energy in the building field.

- **Resource utilization of building envelope.** Wind energy and solar energy are characterized with low density and scattered distribution, thereby mainly developing in a distributed manner. Building roofs and vertical surfaces exposed to sufficient solar radiation would become the best places to install the solar photovoltaic system. It has been roughly estimated that the roof surface of civil buildings in China having access to the solar photovoltaic system exceeds 10 billion m^2 and the annual energy output reaches 2 trillion kWh. Building exteriors shall be taken as a main resource for building power consumption and a new approach to building energy saving.

- **Sustainable development of urban energy system.** Highly penetrated renewable energies pose severe challenges to the safety and reliability of the urban energy system. Power supplies, nets, loads and energy storage shall be subject to interaction control, and several energies (such as thermal and electrical) shall work together to cope with the challenge and achieve sustainable development of the urban energy system. It is becoming the new sector of building energy saving to explore distributed building energy storage and adjustable loads and to improve the flexibility of building energies, except energy efficiency upgrade.

- **Economic revival of rural and western regions.** Rich land resources in rural and western regions are the foundation to develop such renewable energies as solar energy, wind energy and biomass energy. Electrification of domestic hot water, heating and farming equipment can therefore improve energy efficiency and decrease the utilization of scattered coal, playing a significant role in improving the living conditions of farmers, reduce environmental pollution and promote rural economic development.

■ Rapid development of building electrification in China

- **Trend of building electrification in China.** Until 2017, the building electricity consumption amounts to 26% of total electricity consumption, the building per capita electricity consumption 1186kWh and the building electrification rate 48%. Compared with 2001 data, the building per capita electricity consumption increases by 4 times and the building electrification rate rises by 29%.

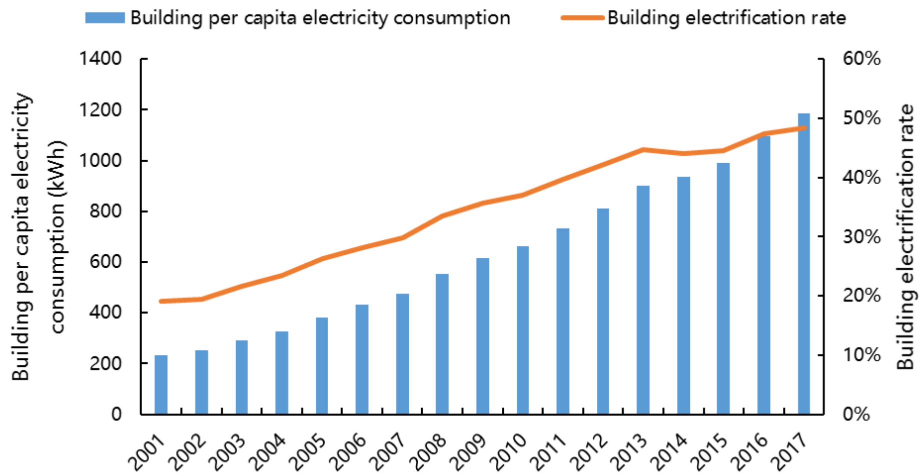

Figure I Building Per Capita Household Electricity Consumption and Building Electrification rate

- **Significant electrification difference in provinces and cities.** The building per capita electricity consumption relates to different household economic consumption levels. In Tier 1 cities such as Beijing and Shanghai, the building electricity consumption reaches 3000 kWh per capita, more than 2 times of the average national amount. In addition, the heating demand differs in the south and north, resulting in a significantly different building electrification rate.

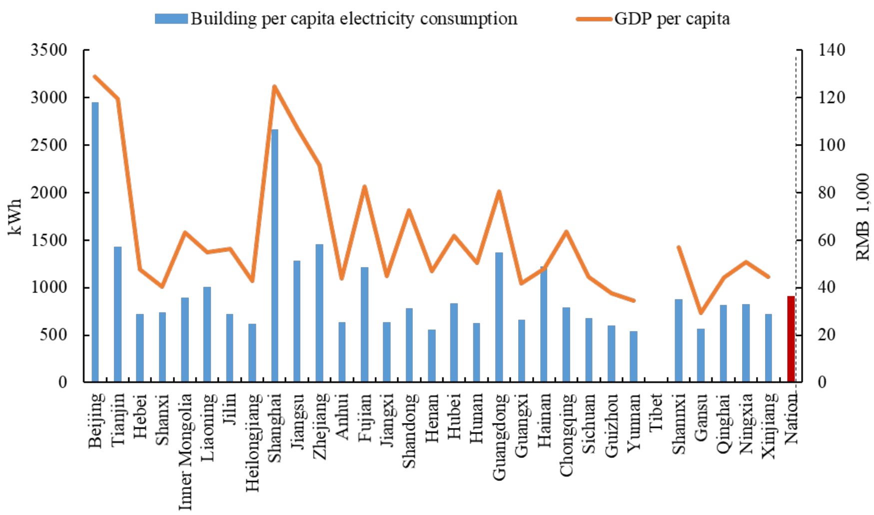

Figure II Building Per Capita Electricity Consumption and Household Consumption Level in Provinces and Cities

- **Gap in Building electricity consumption between China and Developed Countries.** China witnesses a significant gap in building per capita electricity consumption compared with developed countries, and thereby a great potential in building electrification growth. However, it does not mean that the related number may rise to the level of developed countries, because the difference in energy utilization and upgrade of energy efficiency shall be considered.

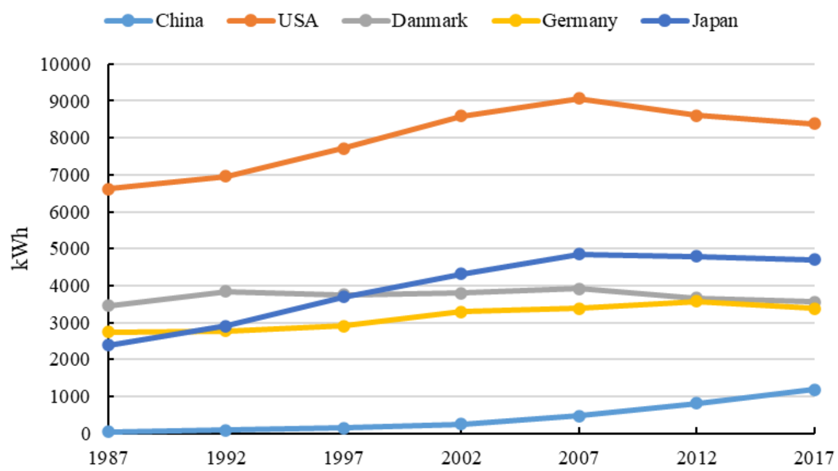

Figure III Building Per Capita Electricity Consumption in China and Developed Countries

■ Building Electrification Sweeps around the World

- **Building electrification pushed by California contributes to the goal of carbon neutral by 2045.** Berkeley took the lead in enacting laws to stop using natural gas in new buildings in 2019. More than 25 cities and towns then followed Berkeley to take measures demanding or strongly supporting electrification in new buildings. The other 50 cities and towns are considering the formulation of similar laws and regulations to push forward building electrification. As required by 2019 Los Angles Sustainable Development Plan, the goal of zero emission for new buildings shall be reached by 2030 and all existing buildings shall be subject to zero emission reconstruction by 2050. San Jose aims to achieve the goal of 47% building electrification.
- **Heating electrification in Europe aims to achieve the goal of 86% carbon emission reduction in heating and cooling sectors.** The European scholars have established Heat Roadmap Europe 4 in 2018. In the cities and towns with centralized heat supply, the heat supplied by large heat pumps shall reach to 25% of the total heat. For the regions inaccessible to centralized heat supply networks, the heat supplied by high-efficient heat pumps shall be close to 50% of the total heat in that region. The carbon emission in the field of heating and cooling sectors will reduce by 4.34 million tons or 86% by 2050, compared with that of 1990. The new carbon emission reduction technology allows decreasing the annual investment cost by 6%, compared with the regular carbon emission reduction technology. The fossil energy consumption in the field of heating and refrigeration will reduce by 10.4 TWh in 2050, compared with that of 2015. At the same time, natural gas and

low-efficient heating technologies shall be fully replaced, and the heating and refrigeration technologies bring about 100% renewable energies in the whole energy system.

■ Demand side: Building electricity consumption and electrification rate upgrade technology

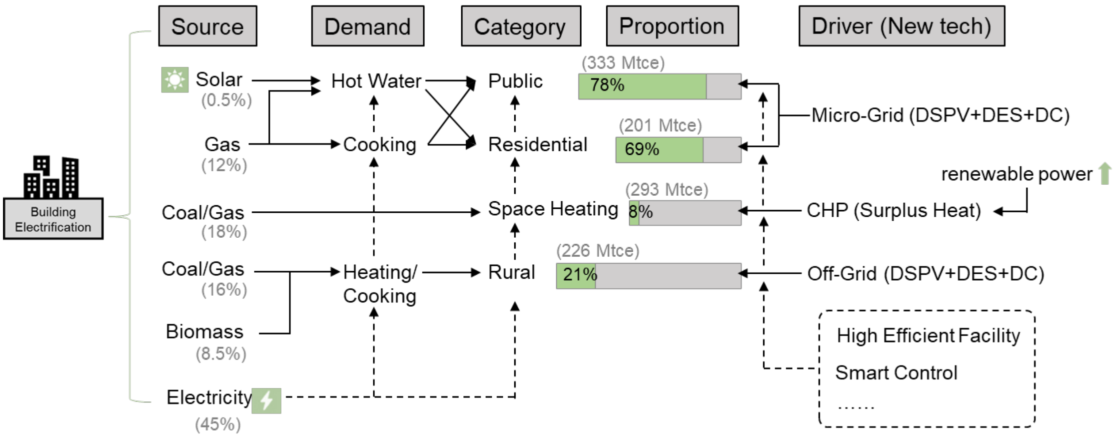

Figure IV Technical Approach to Increasing Building Electrification Rate

Natural Growth of Electricity Consumption The building electricity consumption relates to the household consumption level. As the living conditions keep improving, the number of electrical appliances and using frequency shall witness natural growth. If the average electricity consumption nationwide is close to that in Tier 1 cities, i.e., about 2800 kWh of the building per capita electricity consumption, the nationwide building electricity consumption shall exceed 4 trillion kWh. At the same time, Building energy saving policies continue to reduce energy consumption in building heating, almost offsetting the energy consumption growth resulted in by rise in the building heating surface of the northern region. The building electrification rate shall therefore see natural growth.

- **Electrification of Domestic Hot Water.** For the Centralized domestic hot water system of residential buildings and public buildings, heat loss is significant. Scattered electric water heaters shall be then used to achieve efficient energy saving and promote the utilization of renewable energies. The domestic hot water system of public buildings shall be separated from the steam heating system. The highly-efficient electric heat pump shall be used as a heat source and obvious energy saving benefits expected.

- **Electrification of Space Heating in North Urban Areas**. District heating networks are popular in north urban China, which provide convenience for recovering the surplus heat inside power plants and industrial plants. Compared with electric heating technologies such as the electric heat pump, the surplus heat is more efficient and economical; thus, it shall be taken as a priority for centralized heating in north urban China. The electric heating technologies can be used for an additional heat supply when surplus heat is not enough, accounting for a certain percentage in the centralized heat supply system in north urban China, but full electrification shall not be pursued, especially in consideration of the seasonal decrease of renewable energy in winter .

- **Electrification of Space Heating in North Rural Areas.** Electric heating technologies as the air-source heat pump are promoted in north rural areas, which is an effective approach to replacing scattered coal and reducing atmosphere pollutant discharge. It should be noted that the thermal insulation properties of buildings shall also be strengthened to avoid increase in power costs for farmers and the capacity of power grids. Electrification shall keep pace with the structural insulation and demand response technologies in north rural residential buildings.

- **Electrification of Cooking.** On one hand, more attention shall be then attached to cooking electrification in public buildings, because more and more urban residents choose to eat out and energy consumption for cooking moves from residential houses to public buildings. On the other hand, it is important to change the cooking habit of households. Cooking electrification guidance is needed. Highly-efficient electric cooking facilities shall be promoted.

■ Supply Side: New Building Power Supply and Distribution Technologies

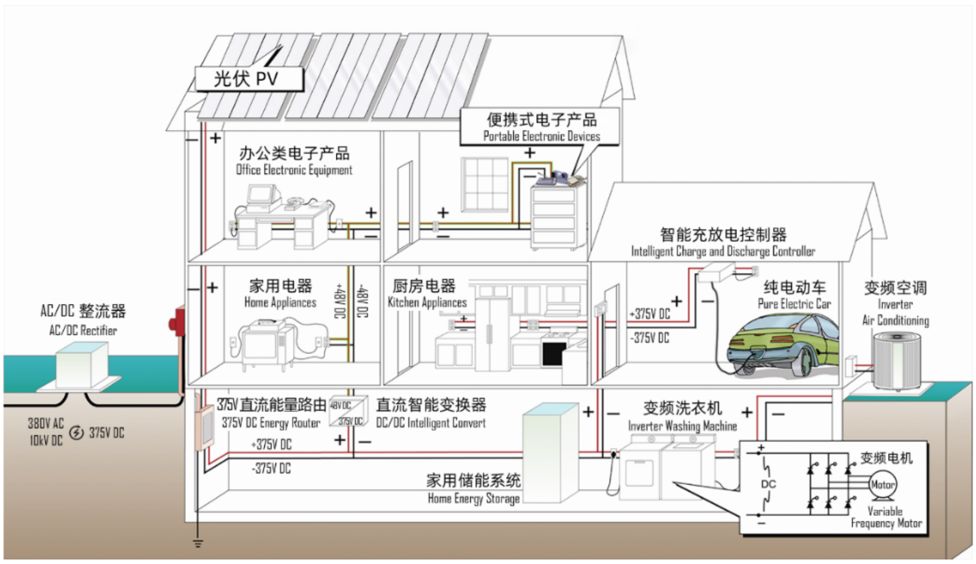

Figure V New Building Power Supply and Distribution Technology

- **Features of the new building power supply and distribution system.** Distributed photovoltaic shall be installed inside buildings. Energy storage batteries shall be provided in the system; adjustable and interruptible smart electric building equipment, including smart air-conditioning, smart lighting and smart charging piles; and an LVDC power distribution system.

- **The advantages of the new building power supply and distribution system.** Compared with the traditional one, power supplies, storage energy and loads were integrated together. The building power demand will be flexible, because more interruptible and adjustable loads are connected. In addition, the LVDC power distribution system will promote energy efficiency, improve power supply reliability, and simplify energy control.

■ Building Electrification Promotes Low-Carbon Development and Industry Upgrade

- **90% of building electrification rate in 2050 is required to reach the goals of 1.5 degree and carbon neutral**. Based on LBNL building energy consumption model, building electrification scenario is built in this project. Under the reasonable increasing trend of building energy demands, two "90%" (building electrification rate 90% and non-fossil power rate 90%) are required to reduce the carbon emission of building sector to 0.55 billion tons. This scenario can satisfy the goal of 2 degree. As for the goals of 1.5 degree and carbon neutral, more aggressive policies on building electrification and building energy demand control should be applied.

- **Carbon emission for buildings will reach its peak by 2030.** Carbon emission of building sector under the electrification scenario will reach its peak around at 2.1 billion tons by 2030.

- **The goal of low carbon development in China is supported.** Building sector carbon emission will keep reducing after 2030 and stand at lower than 1 billion tons CO2 per year by 2050, 75% of the number under the reference scenario, supporting the energy system in China meets the goal of carbon emission under the 2K scenario established in the Paris Agreement.

- **Atmosphere pollution treatment.** The NOx and SO_2 emissions under the electrification scenario reduce by 82% and 83% compared with those in 2020, and by 75% and 77% compared with those of reference scenario, respectively.

- **Upgrade of building power supply and distribution industry.** The new building power system pushes forward its core technologies, such as distributed PV, distributed power storage, DC building power distribution, flexible building energy control and energy internet. As calculated by the Alliance of DC Building, the market scale of affiliated industrial chains can reach RMB 0.7 trillion per year.

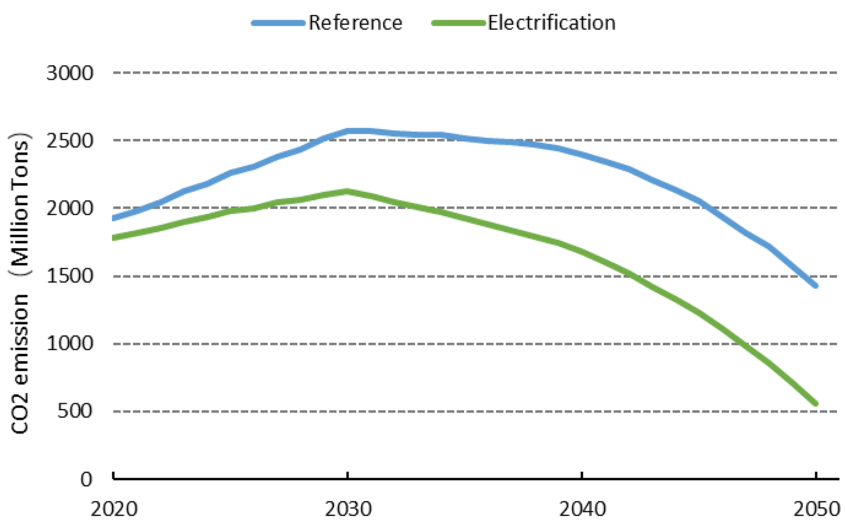

Figure VI CO_2 emission of building sector (including direct emissions in end-use and indirect emissions in power plants)

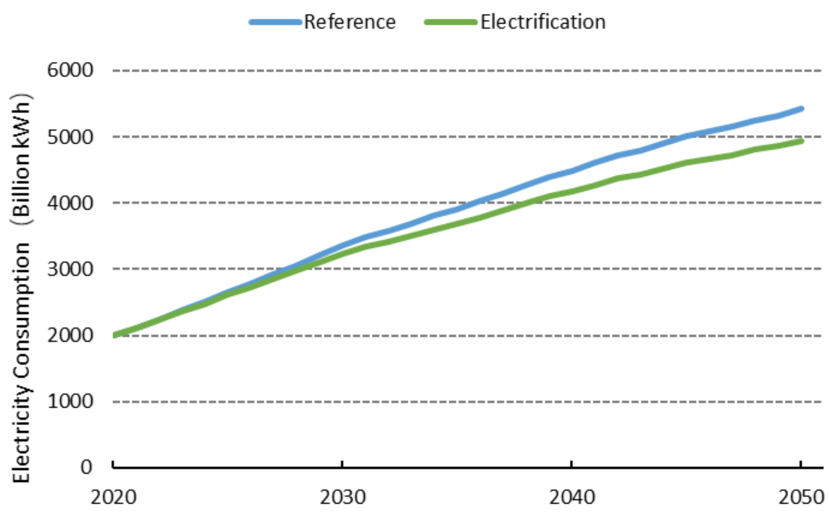

Figure VII Electricity consumption of building sector

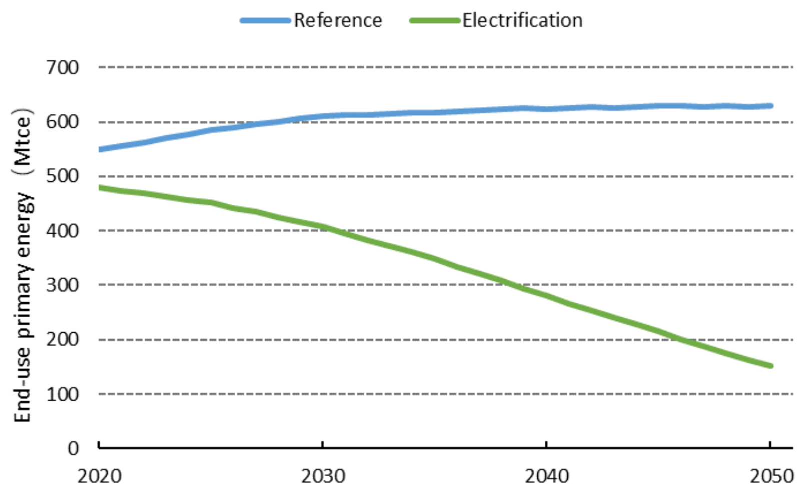

Figure VIII Primary energy consumption in end-use of building sector

■ S.W.O.T. Strategy for Building Electrification

- **SO strategy- Targeting new needs.** Develop high-efficient electrification replacement and the new building power system; improve the efficiency and reliability of the system; achieve building energy control and response to demand; promote urban low-carbon energy transformation and integration of power supply, grid, load, storage and control.

- **WO strategy-Making full use of existing policies and funds.** Establish sample buildings or zones; try new technologies and policies; integrate industrial chains; formulate iterative standards; verify the technology and policy are feasible and acceptable to the customer.

- **ST strategy-Promoting proven technique.** Integrated development of buildings, power grids, traffic and industries allows reducing the technology iteration period and equipment cost. Take the advantages of emission reduction and safety for electrification, to push highly-efficient energy replacement, especially scattered coal in rural areas and coal boilers in cities. Take full use of local distributed renewable energies to reduce the consumption cost of customers, even bringing benefits in villages.

- **WT strategy-Make new policies and funds.** Top planning is given nationally as per the long-term low-carbon development objective, confirming the development approach to building electrification. Financial subsidies and policy support are given to sample projects and innovative technologies. Stimulate electrification replacement; promote technical innovation, equipment R&D and standards preparation for the new building power system.

Figure IX S.W.O.T. Analysis of Building Electrification

Internal factors / **External factors**		**Strengths (S)**	**Weaknesses (W)**
		• Promote renewable energy • Improve building energy efficiency and reliability • Achieve building energy control and response to demand • Integrated development of buildings, power grids, traffic and industries	• Time needed for customer behavior change • Early investment for key equipment R&D • Incomplete standards and policies
Opportunities (O)	• Low-carbon energy transformation • Integration of power supply, grid, load, storage and control • New urbanization, new rural construction and inner economic cycle	SO strategy Targeting new needs • Develop high-efficient electrification replacement and the new building power system; improve the efficiency and reliability of the system; achieve building energy control and response to demand; promote urban low-carbon energy transformation and integration of power supply, grid, load, storage and control • Develop the new building power system in cities and villages; promote new urbanization and rural buildings; rely on domestic industrial chains to improve inner economic cycle	WO strategy Making full use of existing policies and funds • Establish sample buildings or zones; try new technologies and policies; integrate industrial chains; formulate iterative standards; verify the technology and policy are feasible and acceptable to the customer
Threats (T)	• Natural gas development • Economic slowdown pressure • benefits pattern under existing electricity pricing mechanism	ST strategy Promoting proven technique • Integrated development of buildings, power grids, traffic and industries allows reducing the technology iteration period and equipment cost • Take the advantages of emission reduction and safety for electrification, to push highly-efficient energy replacement, especially scattered coal in rural areas and coal boilers in cities • Take full use of local distributed renewable energies to reduce the consumption cost of customers, even bringing benefits in villages with rich renewable energies	WT strategy Make new policies and funds • Top planning is given nationally as per the long-term low-carbon development objective, confirming the development approach to building electrification • Financial subsidies and policy support are given to sample projects and innovative technologies. Stimulate electrification replacement; promote technical innovation, equipment R&D and standards preparation for the new building power system.

■ Objective of Building Electrification

Figure X Objective of Building Electrification

		2018	2025	2035	2050
Power Supply	Urban distributed PV coverage rate	0.5%	1.4%	2.7%	3.0%
	Non-fossil energy rate of building power supply	29%	40%	55%	90%
	Reliability of building power supply	99.94%		99+X%	
Power Consumption	Building per capita electricity consumption/kWh	1180	2000	2600	3400
	Building electrification rate	48%	60%	75%	90%
	Rate of building electricity consumption to total electricity consumption	26%	30%	35%	40%
Project Construction	Building PV install capacity /GW	20	80	300	1000
	Building power storage capacity /GWh	/	0.5	25	300
	Building area of the buildings applying the new Building Power Supply and Distribution Technologies /billion m^2	/	0.05	2	20

- **Short-term: 2020-2025 rapid growth in building power consumption and emerging of new building power system.** During the 14th five-year program, the economic level will keep improving; such sectors as clean heating and domestic hot water are being pushed forward. The building per capita power consumption is expected to be slightly higher than the annual average growth showed for the 13th five-year program and reach 2000 kWh with 60% of the building electrification rate by 2025(calculated as per coal consumption power generation). Urban distributed PV devices will cover 1.4% and Non-fossil power supplies for buildings amount to 40%. The power grid will supply 99% power while the rest of 0.X% will be solved by buildings, ensuring the reliability of power supply. The new building power supply and distribution technologies are still at the initial development stage, mainly relying on national policies to push forward sample projects. It has been forecasted that, by 2025, the buildings applying such technologies will cover 50million m^2; the total installed capacity of PV devices (excluding industrial buildings) will reach 80 GW and the scale of building energy storage stand at 0.5million kWh.

- **Mid-term: 2025-2035 slow growth in building power consumption and booming of new building power system.** During 2025~2035, economic growth will slow down, as well as the building per capita power consumption and the rate of electrification. It is expected that the building per capita power consumption reaches 2600 kWh with 75% of the building electrification rate by 2035 (calculated as per coal consumption power generation). Urban distributed PV devices will cover 2.7% and Non-fossil power supplies for buildings amount to 55%. The new building power supply and distribution technologies will turn out to be mature and prominent in economic benefit. The Chinese government has committed to having a carbon emission peak around 2030. The duration of 2025~2035 will witness a rapid growth of renewable energy technologies and the new building power supply and distribution system. It has been forecasted that, by 2035, the buildings applying such technologies will cover 2billion m2; the total installed capacity of PV devices will reach 300 GW and the scale of building energy storage stand at 25 GWh.

- **Long-term：2035-2050 highly electrified building sector, mature new building power supply and distribution technologies, and highly penetrated renewable energies** During 2035~2050, the building power consumption will still keep a stable growth and electrification constantly push forward. It is forecasted, by 2050, that all buildings will be electrified, except in the northern regions adopting combined heat and power generation and rural areas adopting bio-mass; the building per capita power consumption reaches 3400 kWh with 90% of the building electrification rate (calculated as per coal consumption power generation). Urban distributed PV devices will cover 3.0% and Non-fossil power supplies for buildings amount to 90%. The new building power supply and distribution technologies will be adopted in a large scale and it is forecasted that, by 2050, the buildings applying such technologies will cover more than 20 billion m2; the total installed capacity of PV devices will reach 1000 GW and the scale of building energy storage stand at 300 GWh.

Suggestion on building electrification policies

- **Confirm the goal of building electrification.** Such a goal shall be indicated in special plans, such as energies, electric power, renewable energies, response to climate change, energy-saving and emission reduction, building energy saving and green buildings.

- **Complete technical standards and codes.** Building electrification related technical standards and codes shall be prepared, such as DC buildings, power grid friendly buildings, energy internet users.

- **Strengthen research on building electrification technologies.** The new building power supply and distribution system, which integrates distributed PV, distributed storage batteries, flexible power consumption and loads and LV DC power distribution technologies shall be studied.

- **Strengthen research on building electrification systems.** The following shall be studied, i.e., the electric price system adapted to distributed energies and energy storage development, integrated design and operation technologies for buildings and electric car charging piles, interaction technologies of buildings and urban power grids and the compensation system.

- **Promote the construction of sample projects.** Establish sample projects applying new electrification technologies; plan and implement highly-efficient electrification technologies and new building power supply and distribution technologies; put new policies into trial.

- **Support the development of new building power supply and distribution industrial chain.** Financial support shall be given at the initial development stage of building DC power distribution and building energy storage.

- **Stimulate stakeholders to build electrification.** Strengthen publicity to allow those entities of importance and strong influence to understand the way how building electrification develops and its objective. Strengthen guidance for those entities of importance but low influence to gradually be involved in building electrification. Attention shall be attached for those entities of strong influence but low importance to understanding the value of building electrification; it may be hard for such entities to consider the role of building electrification from their own value or benefit.

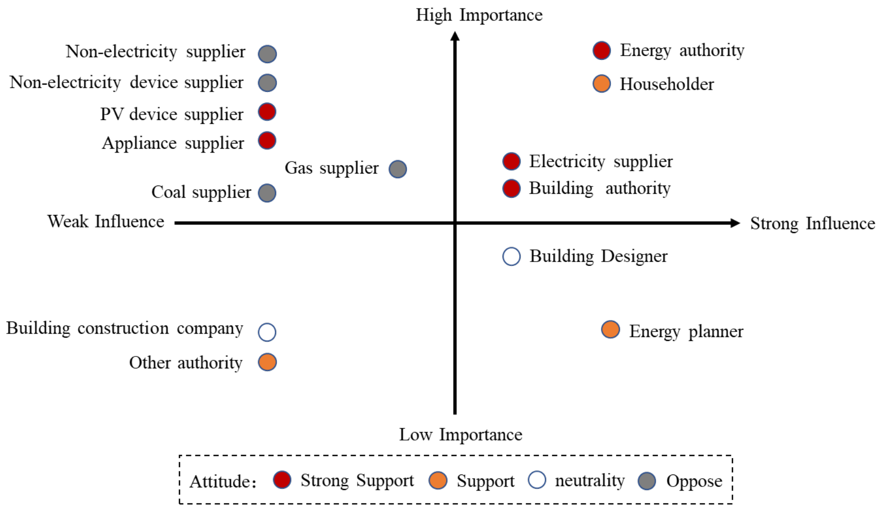

Figure XI Stakeholders to Building Electrification

Integrated Development of Building Electrification, Power Grid, Traffic and Industries

- **Building and power grid**. Building is the main consumer in the urban power grid. Building electrification upgrades the amount of power consumption and promotes power consumption growth. The new building power supply and distribution system turns out to be quite flexible. Power decoupling and off-grid operation can be achieved to strengthen the reliability of the power system. The power grid supplies 99% of the demand while the building supplies the remaining 0.X% demand based on its feature. In addition, building flexibility upgrade also allows the distributed building energy system to be involved in peak and frequency modulation for the urban power grid, absorbs more renewable energies, reduce the building load peak and ease the pressure imposed by the power grid capacity increase in a building complex and the peak modulation of the urban power grid.

- **Building and traffic.** New energy vehicles are transferring from the B-end market to C-end market and the daily average parking time reaches 80%, therefore quick charging is not necessary. If we also take into account the influence of charging on the load peak of a power transformer, slow charging shall be adopted for charging piles around the building and supported by the technologies of orderly charging and two-way charging/discharging. The power grids and charging piles of residential building complexes and public buildings shall be considered and constructed together. Power consumption of buildings and traffic shall be highly coupled.

- **Building and industry.** Building electrification replies on such new building power supply and distribution technologies as PV, energy storage and DC power distribution. Industries and civil buildings are two application scenarios in a city. New building power supply and distribution technologies may develop between different scenarios. For example, the LV DC power distribution technology is mainly used in the building scenario to promote the application of building PV and energy storage and strengthen power flexibility in buildings; in the industrial scenario to solve voltage sag and ensure the reliability of power supply. Energy density and driving safety shall be mainly considered for storage batteries in the vehicle industry; storage economy and firefighting safety shall be mainly considered in the building scenario.

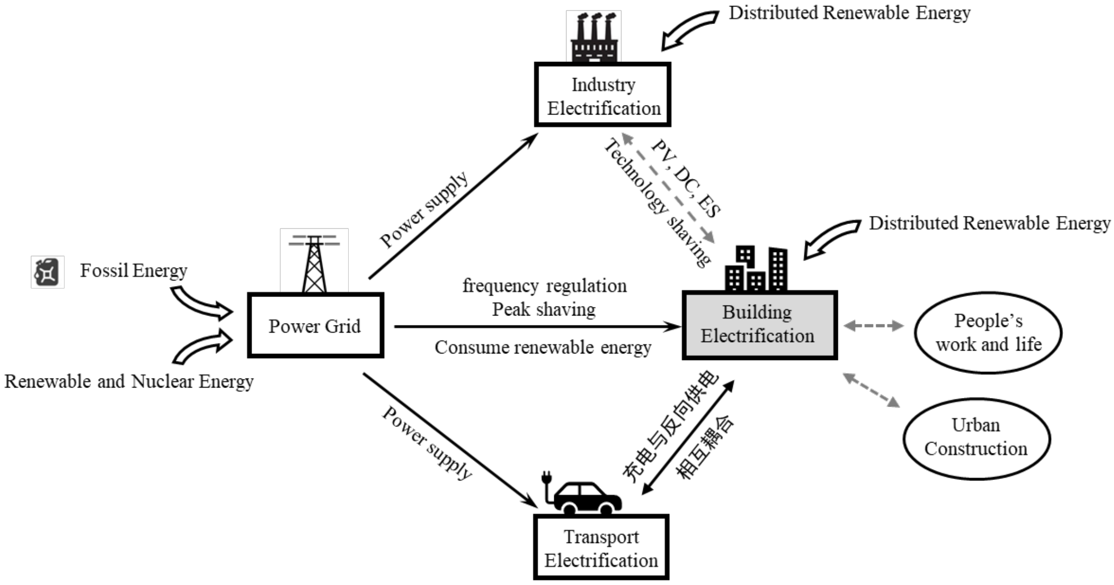

Figure XII Interaction Relation of Building Electrification, Power Grid, Traffic and Industries