# 中国光储直柔建筑发展战略路径研究
# （二期）

# Research on the Strategic Path of PEDF Buildings in China (Phase II)

## 子课题 8：光储直柔区域级应用示范研究
## Task 8: Regional Application and Demonstration of PEDF

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**2023 年 12 月 15 日**

**State Grid Energy Research Institute, State Grid (Suzhou) City and Energy Research Institute, Tsinghua University**

**Dec 15, 2023**

## 致谢

本研究由清华大学统筹撰写，由能源基金会提供资金支持。

## ACKNOWLEDGEMENT

This report is a product of Tsinghua University and is funded by Energy Foundation China.

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# 执行摘要

## 1. 背景及意义

- **区域光储直柔是平抑电网波动、消纳本地可再生能源、实现建筑集群“碳中和”的有效手段。**区域建筑的“光储直柔”系统具有增强电能利用率、实现可再生能源为基础的零碳电力、削峰填谷缓解电网压力、增强电网供电可靠性等优势。

- **“光储直柔”系统在建筑领域进行集成应用仍处于探索研究阶段，大规模推广应用仍面临困难与挑战。**全面推广仍存在产业聚集度不高、建成案例数量少、相关配套技术存在短板、配套激励措施及商业模式不够成熟、有关的标准体系不够健全等难点。

- **光储直柔单项技术成熟度高，单体建筑应用技术领先，跨系统技术研究待突破，区域系统方案亟待实证。**分项技术具备较好的工程应用条件。跨多行业，能源子系统的集成调控、建筑与电网的友好互动、区域内不同建筑能源系统间互联问题等亟待解决。单母线/多级母线为基础的光储直柔系统拓扑结较为成熟，直流母线调节、储能下垂控制、柔性负荷自适应功率控制技术领先。不同建筑楼宇间的能源互联方案有待提出，光储直柔区域规划方案，运行方案及参与电网友好互动方案有待实证。

## 2. 区域级用电需求及典型用电特征研究

- **苏州社会经济发展迅速。**苏州市常住人口 1275 万人，城镇化率 81.72%。2021 年苏州地区生产总值 22718 亿元，人均 GDP 为 177505 元，**三产结构比例为 0.8：47.9：51.3**。近年苏州逐渐调轻调优产业机构，三产占比增加，主要产业集群包括电子信息、装备制造、先进材料和生物医药。

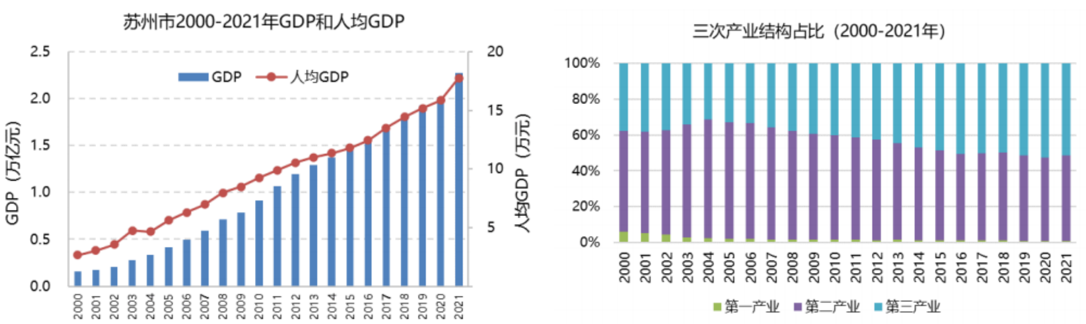


图 I 苏州市 2000 年至 2021 经济发展趋势

- **苏州能源资源供给基本依靠外来支撑，本地发电装机容量稳步提升，总体供应平稳充裕。能源消费持续优化，以煤炭为主的能源结构逐步向多元化、清洁化方向转变。**2020 年苏州市煤炭、天然气、焦炭、成油品、可再生电力和区外来电消费分别占一次能源消费的 59.2%、13.4%、8.5%、10.4%、8.5%。煤炭、石油和天然气几乎完全依赖于外部供应，太阳能、风能、生物质能和地热能资源禀赋也并不丰富，**能源自给率仅为 17.99%**。2020 年苏州市碳排放

量为 **1.76 亿吨 $CO_2$**（外来电力碳排放因子取 558g/kWh）。

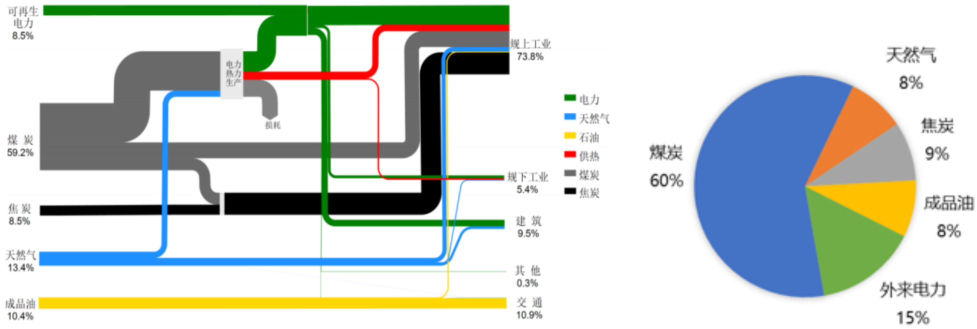


图 II 苏州市 2020 年能流图及碳排放构成

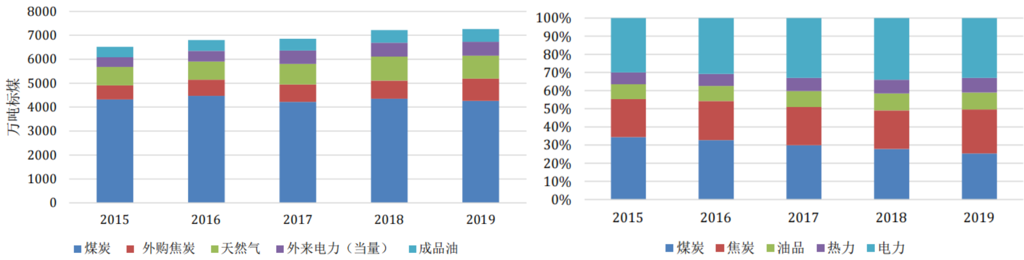


图 III 苏州市 2015 年至 2019 年一次能源消费结构及终端能源消费结构

- **本地能源电力供给结构不断优化。**截至 2021 年底，苏州市各类电源总装机容量 **2482.7 万千瓦**，约占全省装机 16.1%。火电机组装机 **2280.6 万千瓦**，其中煤电机组约占苏州电源装机总量 69.95%。光伏装机 **187.6 万千瓦**，约占苏州电源装机总量 7.56%，分布式光伏发电累计装机 166.35 万千瓦。电网侧储能电站项目 3 个，储能电站充放功率达 13.86 万千瓦，总容量达 24.2 万千瓦时。

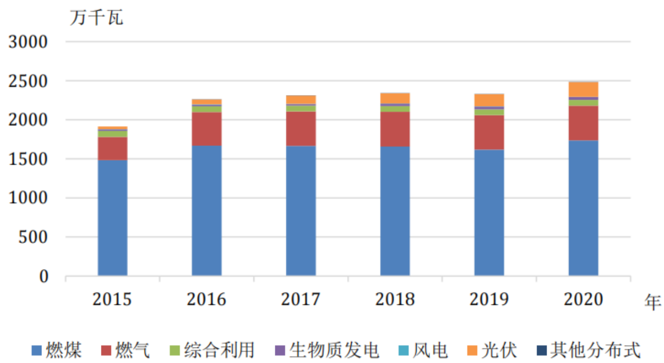


图 IV 苏州市能源电力供给结构

- **能源设施更加完善，保障水平显著提升。**区外电力接纳能力显著提升。1000kV 特高压交流淮上线，与±800 千伏特高压直流锦苏线，±800 千伏特高压直流建苏线，形成全国首个"一交两直"城市电网，有效提升苏州区外电力接纳和应急保障能力。**2021 年区外来电 560 亿千瓦时，**区外受电能力提升至 1090 万千瓦，**占比达到全市最高电力负荷的 1/3**。预计到 2025 年，苏州区外来电超过 900 亿千瓦时，其中清洁电力占比达到 50%。

- **高耗能行业能源消费居高不下，工业部门电力消费占比极高。**苏州 2021 年全行业年用电总量为 1685.3 亿 kWh，人均用电量 13218kWh/人。2021 年第一产

业用电量 3.19 亿 kWh ，第二产业用电量 1284.54 亿 kWh ，本年度工业电量在全社会用电中的占比为 75.4%；第三产业用电量 237.92 亿 kWh ，城乡居民生活用电量 159.62 亿 kWh。

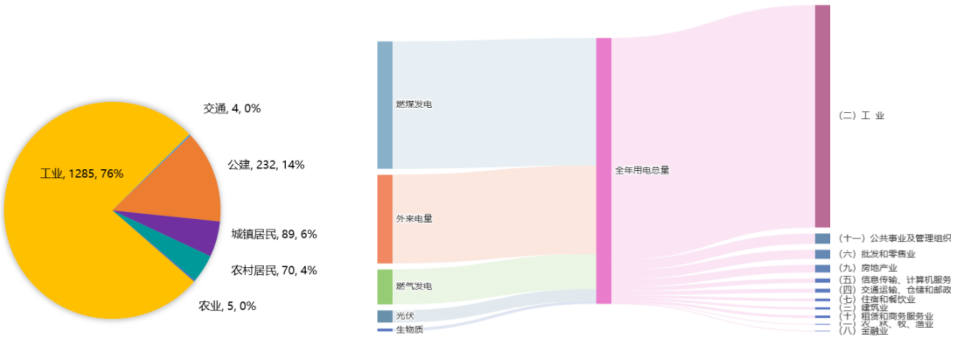


图 V 2021 年苏州分行业年总用电量及结构

- **各行业用电特征，日内用电负荷峰谷差主要由建筑领域造成。**农业用电低谷时期从 11 月中旬到次年 5 月初，高峰期为 7、8 月，高峰季用电约为低谷季的 3 倍。工业用电负荷全年基本平稳，春节、中秋和国庆部分工厂停产负荷明显下降，且存在明显以星期为周期的波动，休息日负荷为工作日的 95%。交通用电负荷主要为电气化铁路。建筑用电由于夏季空调制冷和冬季电采暖存在两个高峰，住宅建筑高峰季用电约为低谷季的 3 倍，公建高峰季用电约为低谷季的 1.5 倍。**空调季工作日峰值一般在 2500 万 kW 左右，最低值在 1700 万 kW 左右，峰谷差主要由建筑造成。本年度最高空调负荷占全市用电负荷比例达到 38.9%。**

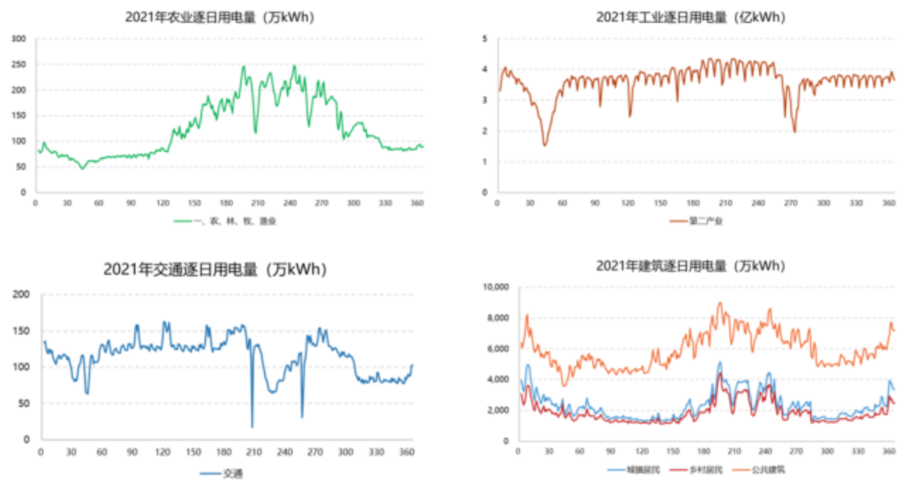


图 VI 2021 年苏州分行业逐日用电量特征曲线

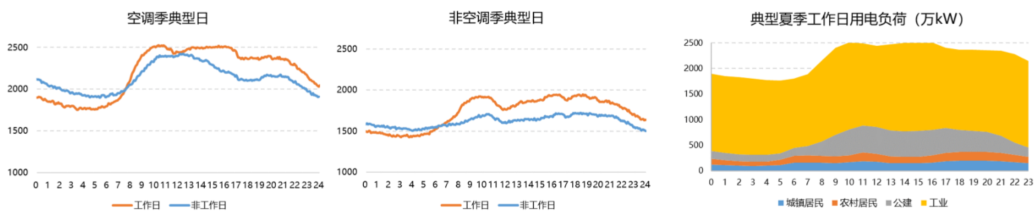


图 VII 典型日电力负荷特征

- **“点尖峰”负荷给电力平衡带来巨大压力。**近年来，华东电网、江苏电网用

电负荷连创新高，电力平衡偏紧；高峰负荷呈明显的“点尖峰”特性。**电网负荷大于 95%、97%当年最大负荷占全年时长比重分别为 0.6%、0.3%。**第三产业和居民生活用电（降温负荷）比重提高将会进一步增加负荷峰谷差。加之电源侧新能源装机比重增加，电力系统运行不确定因素进一步增多。

- **非生产性负荷占尖峰负荷比例较高。** **空调等非生产性负荷**的急剧增长已成为电网高尖峰负荷的主因。2020 年苏州电网夏季**空调负荷**约为 781 万千瓦，占当年最高负荷的 **30%**。空调等非生产性负荷具有明显的季节性和时段性特点，与电网峰谷差具有强关联性，导致**电网最高负荷 95%以上仅为 20-70 小时左右**。按照每 100 万千瓦投资 95 亿元估算，电厂和电网的建设的投资巨大，造成了社会资源的极大浪费。

- **空调负荷柔性调控潜力亟待挖掘。**典型日空调季工作日负荷峰值在 2500 万 kW 左右，最低值在 1700 万 kW 左右，非空调季负荷峰值为 2000 万，最低值 1400 万。空调季与非空调季典型日负荷差在 200 万到 700 万间，考虑调度负荷最大日空调负荷电量更高，**空调负荷约占全市负荷 20%至 35%左右**。苏州每年约承担江苏省迎峰度冬度夏期间 1/4 的电力缺口，根据气温波动情况，缺口基本在 200-500 万千瓦之间，考虑到空调负荷热惯量及人体舒适度区间，其柔性调控潜力巨大。

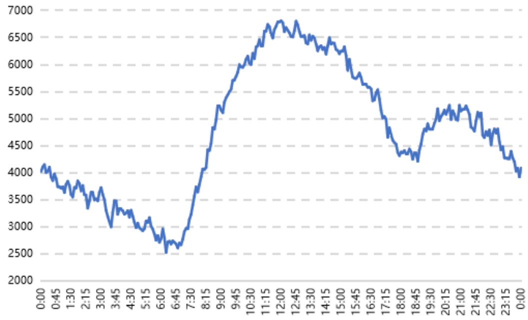


图 VIII 空调季与非空调季典型日负荷差

- **本地光伏资源亟待开发。**《苏州市能源发展“十四五”规划》提出到 2025 年，可再生能源发电装机容量达 **533 万 kW**，其中光伏发电 **460 万 kW**。苏州屋顶分布式光伏总装机潜力约为 **43.5GW**，年发电量 **496 亿 kWh**，根据计算机视觉技术和遥感卫星影像数据，苏州市屋顶总面积约为 5.1 亿平米，按照居民公建可安装光伏板占比 30%，工业建筑占比 70%，分散建筑占比 50%计算，可得到屋顶光伏安装面积约为 2.9 亿平米。

| 区县名称 | 居民+公建 | 工业 | 分散建筑 | 合计 |
|---|---|---|---|---|
| | 万平米 | 万平米 | 万平米 | 万平米 |
| 虎丘区 | 1746 | 1618 | 104 | 3468 |
| 吴中区 | 1880 | 3276 | 732 | 5887 |
| 相城区 | 1105 | 2089 | 316 | 3509 |
| 姑苏区 | 1030 | 136 | 177 | 1343 |
| 吴江区 | 1998 | 6423 | 1407 | 9828 |
| 常熟市 | 951 | 4279 | 1074 | 6304 |
| 张家港市 | 2579 | 4431 | 875 | 7884 |
| 昆山市 | 1034 | 6319 | 644 | 7998 |
| 太仓市 | 1260 | 2714 | 612 | 4585 |
| 合计 | 13583 | 31285 | 5940 | 50807 |

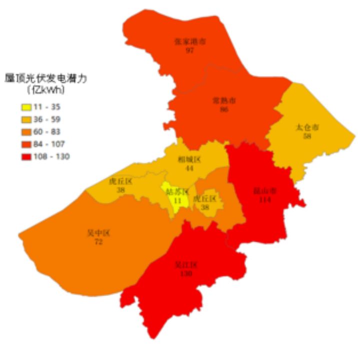


图 IX 各区三类屋顶面积及屋顶光伏发电潜力

- **区域电力负荷柔性调节特征。**以冬季典型日负荷曲线为参考，负荷峰值主要为午峰及灯峰两个极值点，其中**午峰期间压降空间较大**，非连续性型生产企业可调柔性负荷资源多，光伏发电功率处于高位，而**灯峰期间柔性可调资源稀缺**，大多是由于工厂晚班、三产及居民生活用电负荷提升造成，且新能源出力快速跌落，**柔性负荷资源亟待挖掘**。

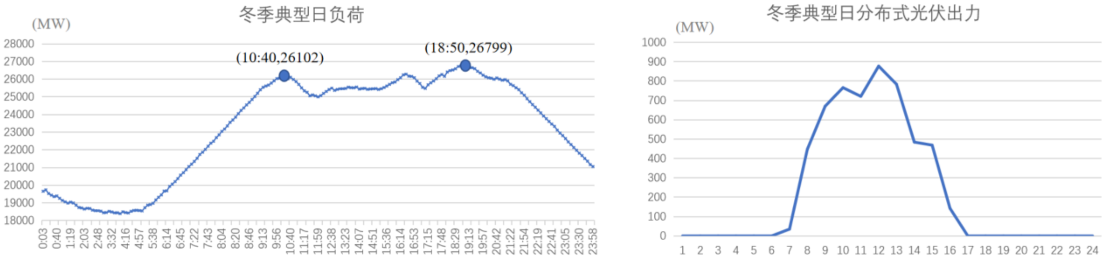


图 X 冬季典型日负荷曲线及光伏出力曲线

- **典型行业负荷特征。**以典型工作日负荷曲线为例，工业负荷呈现**连续生产、多班制等，负荷总量大，多班制负荷波动特征明显**。公共机构负荷变化与工作时间相关，**高峰多集中在白天，空调及照明负荷占比高**。商超餐饮服务业负荷与人员活动相关，**晚间负荷持续时间长**，空调负荷占比高。

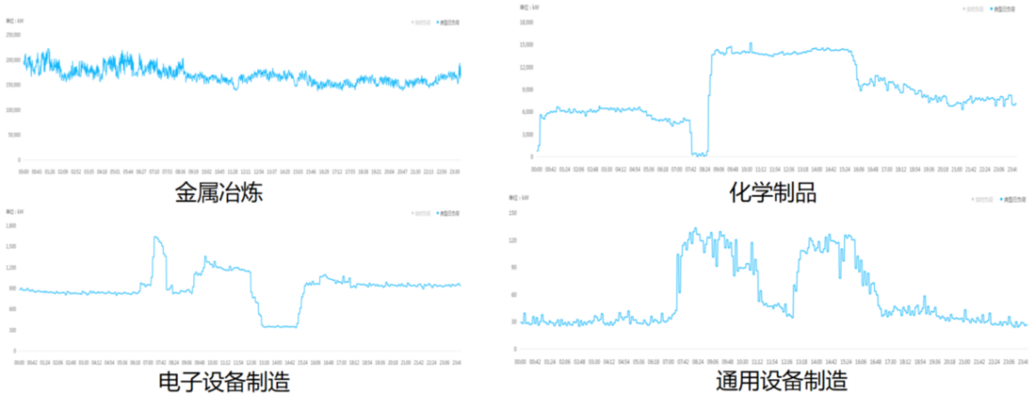


图 XI 工业行业典型日负荷曲线

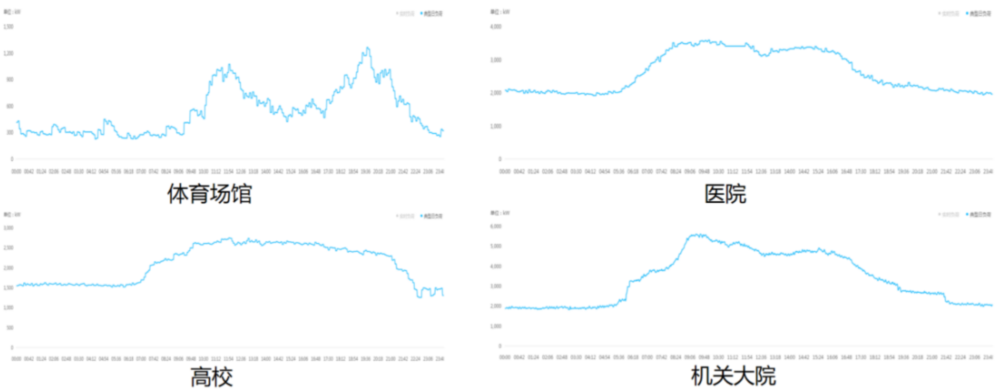


图 XII 公共机构典型日负荷曲线


图 XIII 商超餐饮服务业典型日负荷曲线

## 3. 区域级光储直柔建筑助力零碳电力系统规划方案

- **“十四五”期间苏州能源结构预测。煤炭**占比持续下降，2025 年降至 **49%**左右。**天然气**需求增长平稳，2025 年占比 **21%**左右。**油品**需求增长减缓，2025 年占比 **13%**左右。**非化石**能源需求总量及在一次能源需求中的比重稳步增长，油品需求达峰、天然气需求趋于平稳，2025 年非化石能源占比上升至 **15%**。

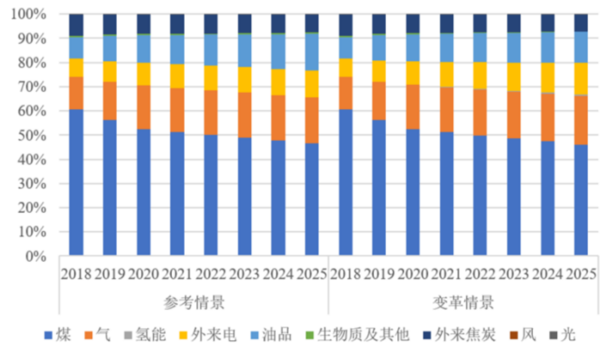


图 XIV “十四五”苏州一次能源结构变化预测

- **终端能源需求总量预测。**苏州终端能源需求总量增速显著放缓，**2025 年进入峰值平台期。**在用能结构优化、先进节能技术推广、能源服务效率提升等措施的推动下，苏州终端能源需求总量增速减缓，终端能源需求总量在 2025 年前后达到峰值。

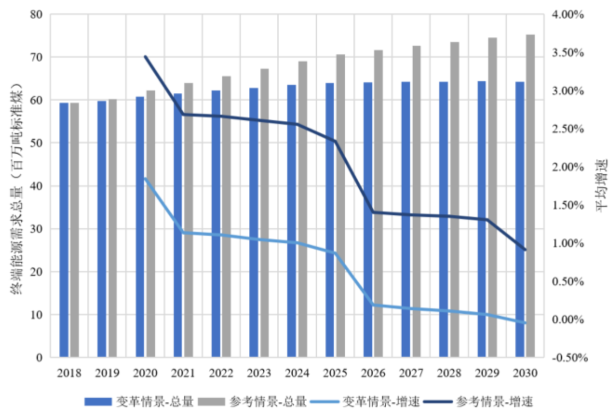


图 XV 终端能源需求总量发展趋势研判

- **终端能源需求结构预测。苏州终端用能结构中电能占比上升幅度最大，煤炭占比大幅下降，天然气和油品占比缓慢上升。**终端用能结构中电能占比 2025 年上升至 33%左右。在 2020 年到 2025 年期间煤炭减量替代速度加快，其在终端能源需求中的占比从 2020 年的 22.8%下降至 2025 年的 20.2%左右。天然气消费保持缓慢下降，油品消费进入峰值平台期。油气消费占比在 2020 年为 24.6%左右，2025 年上升至 26.3%左右。

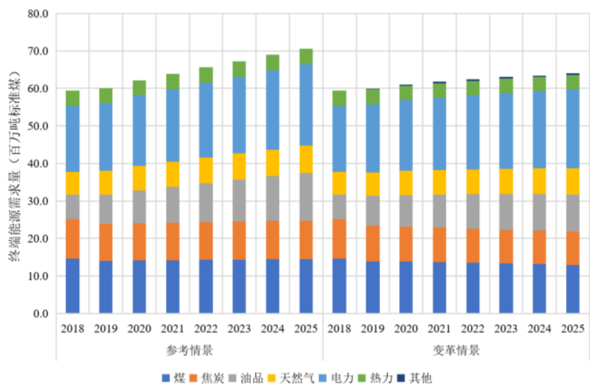


图 XVI 终端能源需求结构发展趋势研判

- **终端分部门能源需求量。**苏州终端能源需求的部门结构缓慢向均衡化演进，建筑部门和交通部门成为增长主体。随着工业产值增速的减缓、工业产业结构和用能技术的优化升级，苏州工业部门的终端能源需求占比稳步下降，建筑部门和交通部门用能占比持续上升。能源变革情景下，**建筑、交通、工业**部门用能占比在 2020 年约为 11：12：77，2025 年约为 **12：16：72**。

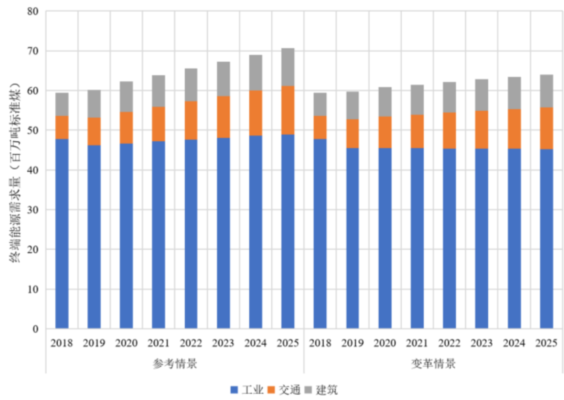


图 XVII 分部门终端能源需求总量发展趋势研判

- **区域电力系统负荷特征。**受电源结构制约，光伏及综合利用（沼气、余热余压）发电峰值仅占负荷峰值的 **8%**，而区外来电及火电的峰值均可以达到负荷峰值的 **50%**。区外来电调度依据主要是基本使其变化规律与全省整体负荷特征类似，其余部分主要由火电机组补足。

- **未来区域电力系统负荷预测。**当前，区域电力负荷呈现**鸭子曲线**特征，但由于新能源装机占比少，鸭子形状不明显，未来随着光伏装机容量的大幅增加，区域电力系统负荷曲线在午间的鸭子曲线特征会逐步凸显，随着电力达峰和碳达峰，为了最大程度利用电网现有配电资源，使得区域负荷与新能源发电时间段更吻合，区域调度负荷在鸭子曲线基础上，应更多的增加午间负载，

适当减小晚间负荷，**负荷曲线最终形成帽子曲线的特征。**

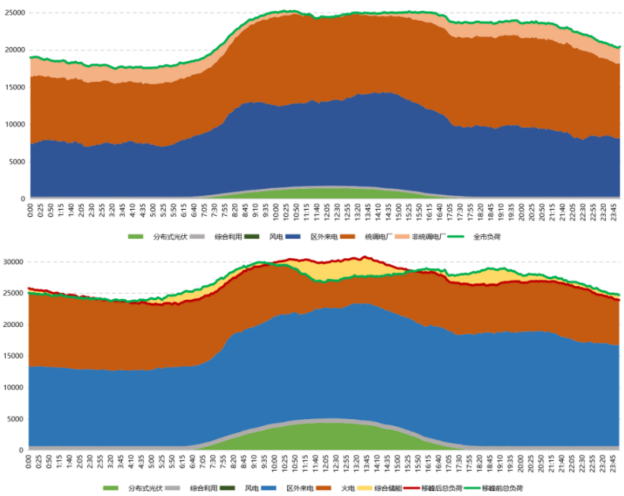

图 XVIII “鸭子曲线”到“帽子曲线”

- **未来区域电力系统零碳发展规划。**苏州将从推进新能源大规模开发利用、推进电网交直流混联升级、推动全社会高度电气化与系统级能效提升、推进新型储能技术应用、加快数字化技术攻关与应用、服务电力配套市场升级等方面，推动新能源发展为装机主题、推动新能源发展为电量、电力主体、全社会高度电气化三阶段实现新型电力系统发展。

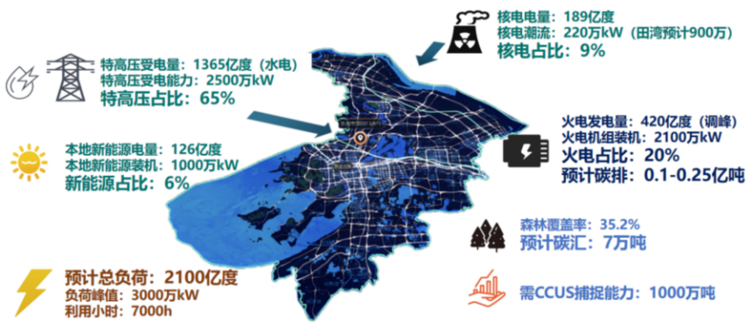


图 XIX 未来区域电力系统零碳发展规划

## 4. 光储直柔示范

- **苏州东吴黄金“光储直柔”项目概况。**项目属于旧厂房改造，建筑规划用于办公、精炼（湿法提存）车间、首饰加工车间、商业出租等，一期工程建筑面积约 28000 ㎡，共三栋建筑。一期工程在主厂房 1#楼与餐厅 3#楼屋顶，及厂区车棚顶建设光伏，二期工程拟建办公 4#楼及厂房 5#，并在屋顶建设光伏。

- **光储直柔系统架构。**一期项目打造“光储直柔”系统应用示范，配置 150kW 柔性能源网关，441.1kWp 光伏，74kW 磁悬浮冷水机、20kW 直流风机盘管等多类直流负荷供电，冷水机可根据母线电压柔性控制。

图 XX 东吴黄金项目一期工程鸟瞰图

- **暖通空调温湿度独立控制系统设计。**磁悬浮冷水机组采用 7℃出水，新风机组向室内送入干燥的新风，带走室内潜热（湿）负荷。磁悬浮风冷热泵机组夏季高温出水，作为冷源送入室内的干式末端，带走室内显热负荷。

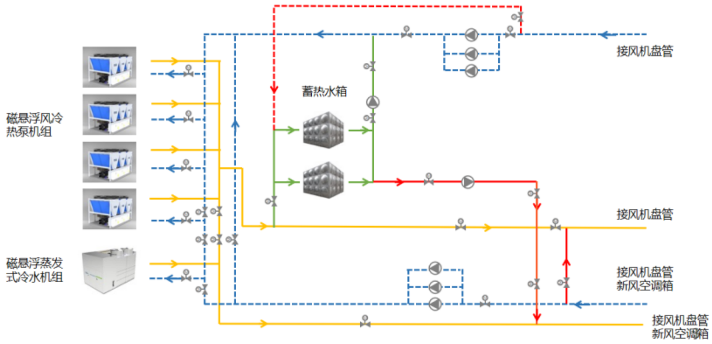


图 XXI 暖通空调系统简图

- **分季节切换系统运行模式。**供冷季节采用“光伏+蓄冷+直流磁悬浮蒸发式冷水机组制冷+其他直流负载”模式，过渡季采用“自发自用，多余光伏发电逆变上网”模式，供暖季采用“光伏+蓄热+风冷热泵制热”模式。

- **典型工况运行情况。**主楼用电与楼内人员活动有关。早晨 6~7 时，晚间 16~20 时光伏发电疲软，需市电补充。天气晴好时日间光伏发电过剩，返送外网。典型工作日单日引进外网电量与返送外网电量基本持平。

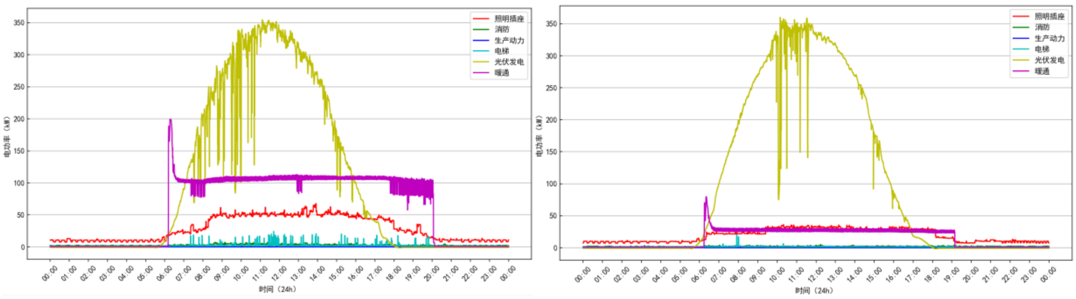


图 XXII 主楼典型工作日及非工作日分项功率曲线

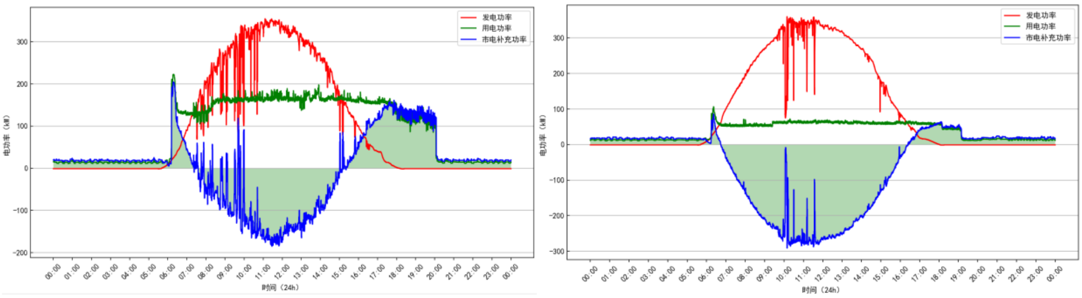


图 XXIII 主楼典型工作日及非工作日市电补充功率曲线

- **工作日用电量与光伏发电量基本持平，非工作日用电量骤减，光伏发电量过剩。**主楼内用电主要为暖通系统能耗，以及办公的照明及插座用电，占主楼总用电量的 80%以上。非工作日用电量相比工作日用电量减少 50%，导致大量光伏电力返送外网。预期通过开启蓄热水箱降低早晚时冷水机组能耗，减少对市电依赖。

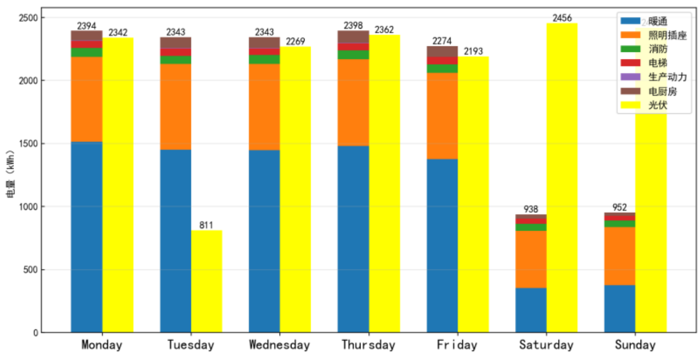


图 XXIV 主楼日用电量堆积柱状图

- **区域级光储直柔建筑协同联动示范。**苏州东吴黄金项目区域内集合办公、精炼车间、首饰加工车间、研发、办公出租、餐厅等业态，混合且分布在不同楼栋内，负荷特征较为完备。

- **跨主体清洁电力消纳探索。**因新变压器与旧变压器同属于一个户号，故园区内可进行跨主体直流母线连接，为未来区域级电力协同互动提供范本参考。

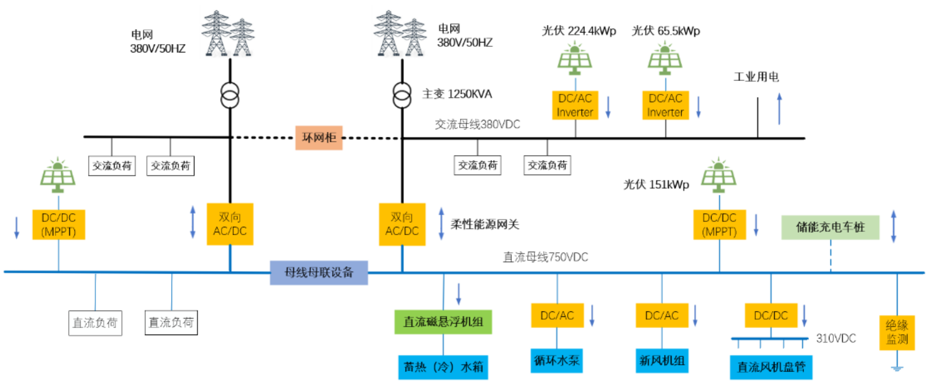


图 XXV 跨主体清洁电力消纳系统简图

## 5. 结论与建议

- **苏州区域清洁电力供给主要依靠外来电，本地可再生能源供应量及利用率提升空间大。**预测未来苏州电网承接外来电力的能力约占全市最高调度负荷的 65%，净受进电量约占全社会用电量 50%。目前，苏州市分布式新能源开发总量偏少，以光伏资源为例，目前仅利用 200 万千瓦左右，随着 BIPV 等技术的推进，苏州未来可利用分布式光伏资源约 500 万千瓦。

- **电力负荷消费方面，未来区域典型日负荷曲线会由“鸭子曲线”向“帽子曲线”演变，区域柔性资源及综合储能资源亟待开发。**随着常规能源机组持续减少，电力供应主要由新能源供应，实际的负荷曲线只能高度近似新能源曲线，峰谷差及峰谷差率等指标的研究都需要重新审视，在传统调峰复制服务及需求响应基础上，基于碳排放因子的区域电力负荷调控模式亟待突破。

- **区域光储直柔应用方面，通过直流配电系统连接光伏、电动汽车有序充电、公共建筑空调负荷集中管理、分布式储能建设等，主动平抑负荷峰值，转移可再生能源电量。**以典型区域电力系统为例，大约需要电网增加约最大调度负荷约 10%左右的综合储能，在政策、技术、补贴到位且用户自愿的理想情况下，典型行业可调节负荷潜力巨大。

# Executive summary

## 1. Background and significance

- **Regional application of PEDF is an effective means of smoothing grid fluctuations, absorbing local renewable energy and achieving "carbon neutrality" in building clusters.** A regional building PEDF system has the advantages of enhancing power utilization, realizing renewable energy-based zero-carbon electricity, reducing peaks and valleys to relieve grid pressure, and enhancing grid reliability.

- **The integrated application of the "PEDF" system in the field of construction is still in the stage of exploration and research, and the large-scale promotion and application still faces difficulties and challenges.** Difficulties still exists in comprehensive promotion, as the industry aggregation degree is not high, the number of completed cases is small, the relevant supporting technologies have short boards, supporting incentives and business models are not mature enough, the relevant standard system is not sound enough and so on.

- **The maturity of the single technology of PEDF is high, the application technology of single building is leading, the research of cross-system technology is waiting to be broken, and the regional system scheme needs to be demonstrated.** Sub-technology has better engineering application conditions. The integration and regulation of energy subsystems across multiple industries, friendly interaction between buildings and power grids, and interconnection between different building energy systems in the region need to be solved. Single bus/multilevel bus-based PEDF system topology is more mature, DC bus regulation, energy storage sag control, flexible load adaptive power control technology is leading. The energy interconnection scheme between different buildings is yet to be proposed, and the PEDF regional planning scheme, operation scheme and participation in grid-friendly interaction scheme are yet to be proved.

## 2. Study of electricity demand and typical characteristics of electricity consumption at the regional level

- **Suzhou's socio-economic development is rapid. Suzhou has a** resident population of 12.75 million, with an urbanization rate of 81.72%. In 2021, Suzhou's GDP was 227.18 billion yuan, with a per capita GDP of 177,505 yuan, and the proportion of the **three-industry structure is 0.8:47.9:51.3**. In recent years, Suzhou has gradually lightened and optimized its industrial organization, with an increase in the proportion of the three industries, and the main clusters include electronic information, equipment manufacturing, advanced materials, and biomedicine.

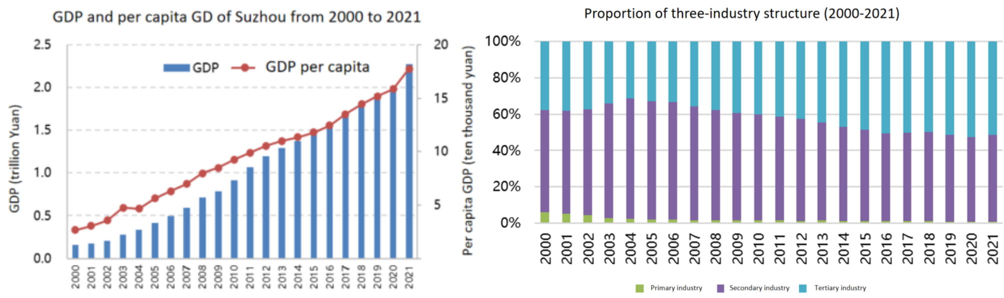


Figure I Economic development trends in Suzhou, 2000-2021

- **The supply of energy resources in Suzhou basically relies on external support, and the installed capacity of local power generation has been steadily increasing, reflecting an overall stable and abundant supply. Energy consumption structure continues to be optimized, with the original coal-dominated energy structure gradually shifting towards diversification and cleanliness.** In 2020, Suzhou's consumption of coal, natural gas, coke, oil products, renewable electricity and electricity from outside the region accounted for 59.2%, 13.4%, 8.5%, 10.4% and 8.5% of the primary energy consumption respectively. Coal, oil and natural gas are almost entirely dependent on external supply, and the endowment of solar, wind, biomass and geothermal energy resources is not rich, with an **energy self-sufficiency rate of only 17.99%**. In 2020, Suzhou's carbon emissions will be **176 million tonnes of $CO_2$** (the carbon emission factor for external electricity is 558g/kWh).

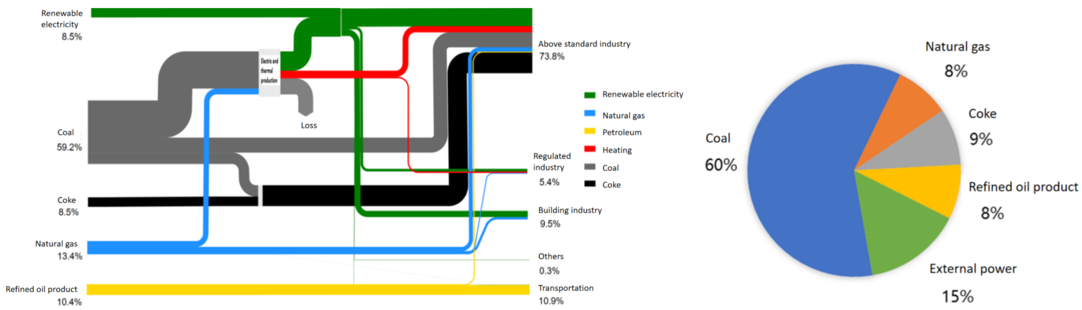


Figure II 2020 Energy flow and carbon emission composition of Suzhou municipality

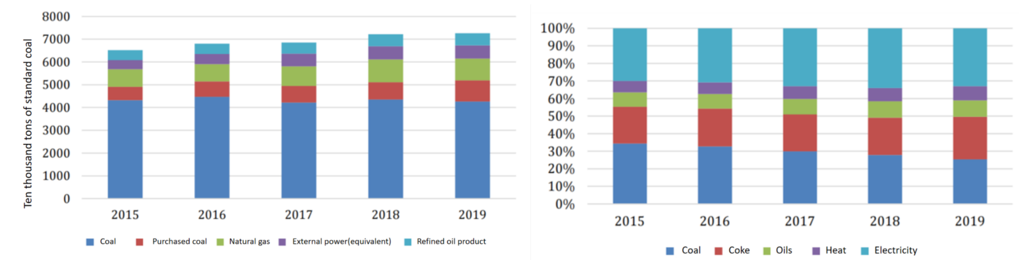


Figure III Primary energy consumption structure and end-use energy consumption structure in Suzhou, 2015-2019

- **The structure of local energy and power supply is continuously optimized.** By the end of 2021, the total installed capacity of all types of power supply in Suzhou **was 24.827 million kilowatts**, accounting for about 16.1% of the province's installed capacity. Thermal power generators installed **22.806 million kilowatts**, of which coal power generators accounted for 69.95% of Suzhou's total power supply installed capacity. Photovoltaic power installed capacity is **1.876 million kilowatts**, accounting for about 7.56% of Suzhou's total power installed capacity, with distributed photovoltaic power generation installed capacity of 1.6635 million kilowatts. There are three grid-side energy storage power station projects, and the charging and discharging power of the energy storage power station reaches 138,600 kilowatts, with a total capacity of 242,000 kilowatt-hours.

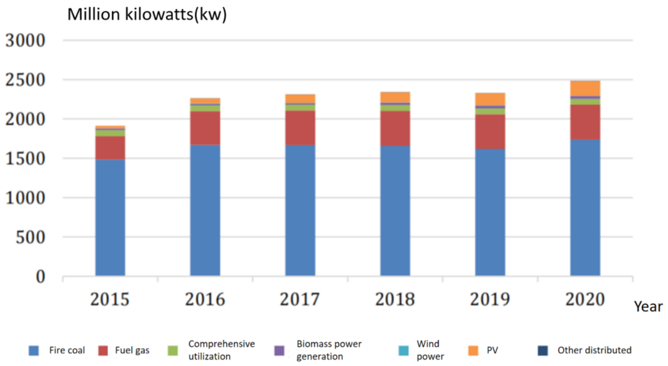


Figure IV Suzhou energy and electricity supply structure

- **Energy facilities are more complete, and the level of protection has been significantly improved.** The capacity of receiving power from outside the district has been significantly improved: the 1000kV UHV AC HuaiLine, together with the ±800kV UHV DC JinSu Line and the ±800kV UHV DC JianSu Line, have formed the first "one-crossing-two-directions" urban power grid in China, which will effectively improve Suzhou's capacity of receiving power from outside the district and guaranteeing emergency situations; the capacity of receiving power **from outside the district will increase to 56 billion kWh by 2021, accounting for 1/3 of the city's maximum power load. In 2021, the external power supply will be 56 billion kWh**, and the capacity of receiving power from outside the district will be increased to 10.9 million kW, **accounting for one-third of the city's highest power load**, and it is expected that by 2025, the external power supply in Suzhou will exceed 90 billion kWh, with clean power accounting for 50 per cent of the total power supply.

- **Energy consumption in high energy-consuming industries remains high, and the industrial sector accounts for a very high proportion of electricity consumption.** In 2021, the total annual electricity consumption of the whole industry in Suzhou will be 168.53 billion kWh, with a per capita electricity consumption of 13,218 kWh per person. 319 million kWh of electricity will be consumed by the primary industry in 2021, and 128.454 billion kWh will be consumed by the secondary industry, with the proportion of industrial electricity in the electricity consumption of the whole society accounting for 75.4% in the current year; the tertiary industry will consume 23,792 million kWh, and the urban and rural residents will consume 15,962 million kWh of electricity for living.

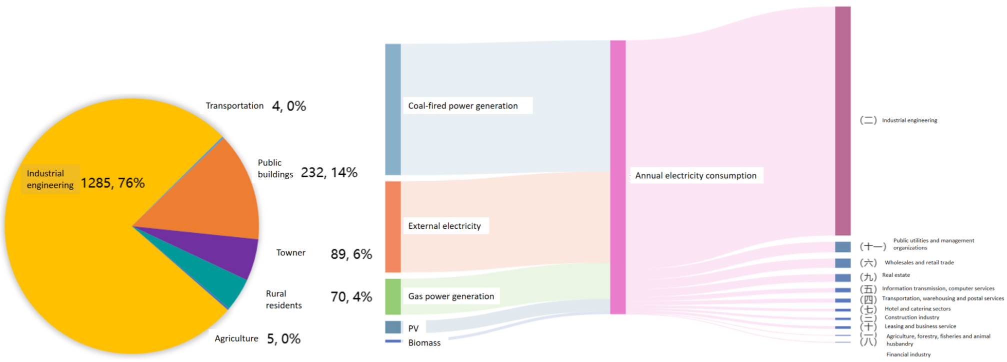


Fig. V Annual total electricity consumption and structure of sub-sectors in Suzhou, 2021

- **Characteristics of electricity consumption by sector. Peak and valley differences in intraday electricity loads are mainly caused by the construction sector.** Agricultural electricity consumption trough period is from mid-November to early May of the following year, with the peak period in July and August. The peak season electricity consumption is about three times the trough season. Industrial electricity consumption load is basically stable throughout the year. Part of the factory shutdown in the Spring Festival, the Mid-Autumn Festival and the National Day result in load dropped significantly, and there exists a clear weekly cycle of fluctuations, showing the rest day load is 95% of the working day. Traffic electricity load is mainly electrified railway. There are two peaks in building electricity consumption due to summer air-conditioning and cooling and winter electric heating. For residential buildings peak season electricity consumption is about three times the low season. For public buildings peak season electricity consumption is about 1.5 times the low season. **The peak weekday value of the air-conditioning season is generally around 25 million kW, and the minimum value is around 17 million kW, reflecting the peak-valley difference is mainly caused by buildings. The highest air-conditioning load during the year accounted for 38.9 per cent of the city's electricity load.**

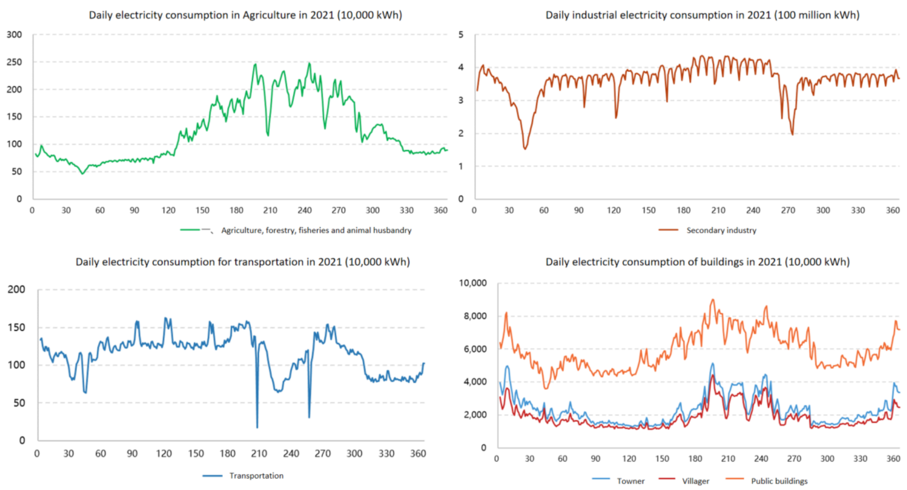


Fig. VI Characteristic curve of day-by-day electricity consumption by industry in Suzhou in 2021

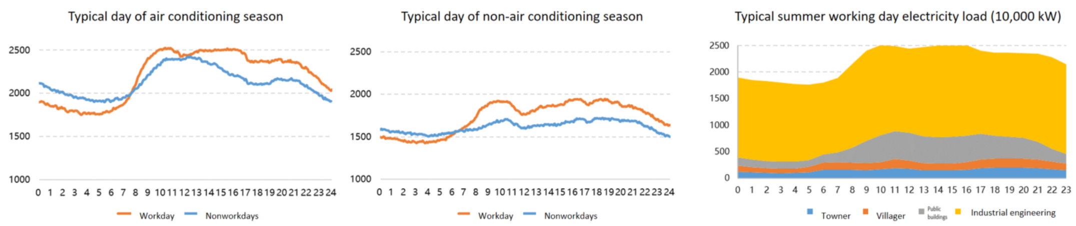


Figure VII Characteristics of electricity load on a typical day

- **The "point peak" load brings great pressure to the power balance.** In recent years, the power load for the East China Power Grid and Jiangsu Power Grid has reached record highs, and the power balance is tight; the peak load has obvious "point peak" characteristics. **Grid load greater than 95 per cent, 97 per cent of the year's maximum load accounted for the proportion of the year's duration of 0.6 per cent, 0.3 per cent respectively.** The proportion of tertiary industry and residential electricity consumption (cooling load) will further increase the load peak-valley difference. Coupled with the increase in the proportion of renewable energy installed on the power supply side, the power system operation uncertainties further increase.

- **Non-productive loads account for a high proportion of peak loads.** The sharp growth of **non-productive loads such as air-conditioning** has become the main cause of high peak loads on the grid. In 2020, the summer **air-conditioning load on the** Suzhou power grid will be about 7.81 million kilowatts, accounting for **30 per cent** of the highest load in that year. Air conditioning and other non-productive loads have obvious seasonal and time characteristics, with strong correlation with the peak-valley difference of the grid, resulting in **more than 95% of the highest load of the grid is only about 20-70 hours**. At an estimated investment of 9.5 billion yuan per 1 million kilowatts, the investment in the construction of power plants and power grids is enormous, resulting in a great waste of social resources.

- **The potential for flexible regulation of air-conditioned loads needs to be tapped.** Typical daily air-conditioning season weekday load peaks at about 25 million kW, with a minimum value of about 17 million kW, and non-air-conditioning season load peaks at 20 million, with a minimum value of 14 million. Typical daily load difference between the air-conditioning season and the non-air-conditioning season is between 2 million and 7 million, and the **air-conditioning** load is even higher when considering scheduling the maximum daily air-conditioning load power, and **the air-conditioning load accounts for about 20% to 35% of the city's load**. Suzhou is responsible for about 1/4 of the power shortfall in Jiangsu Province during the peak winter and summer each year, and according to temperature fluctuations, the shortfall is basically between 2-5 million kilowatts, which has a huge potential for flexible regulation considering the thermal inertia of the air-conditioning loads and the comfort zone of the human body.

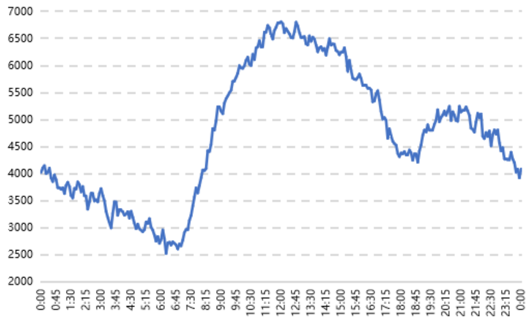


Figure VIII Typical daily load difference between air-conditioned and non-air-conditioned seasons

- **Local PV resources need to be developed.** The "14th Five-Year Plan of Suzhou Energy Development" proposes that by 2025, the installed capacity of renewable energy power generation will reach **5.33 million kW**, of which **4.6 million kW will be** PV. The total installed potential of distributed PV on rooftops in Suzhou is about **43.5 GW**, with an annual power generation capacity of **49.6 billion kWh**. According to computer vision technology and remote sensing satellite data, the total roof area of Suzhou is about 510 million square meters, and according to the calculation of 30% of PV panels that can be installed in residential public buildings, 70% in industrial buildings, and 50% in decentralized buildings, we can get the rooftop PV installation area of about 290 million square meters.

| District name | Residential and public buildings | Industrial engineering | Dispersed building | Total |
|---|---|---|---|---|
| | Million square meters | Million square meters | Million square meters | Million square meters |
| Tiger hill district | 1746 | 1618 | 104 | 3468 |
| Wuzhong district | 1880 | 3276 | 732 | 5887 |
| Xiangcheng district | 1105 | 2089 | 316 | 3509 |
| Gusu district | 1030 | 136 | 177 | 1343 |
| Wujiang district | 1998 | 6423 | 1407 | 9828 |
| Changshu | 951 | 4279 | 1074 | 6304 |
| Zhangjiagang | 2579 | 4431 | 875 | 7884 |
| Kunshan | 1034 | 6319 | 644 | 7998 |
| Taicang | 1260 | 2714 | 612 | 4585 |
| Total | 13583 | 31285 | 5940 | 50807 |

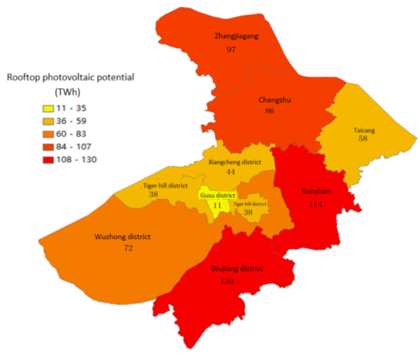


Fig. IX Area of three types of roofs and potential for rooftop PV generation by district

- **Characteristics of regional power load flexible regulation.** Taking the typical daily load curve in winter as a reference, the peak load is mainly the two extreme points of the midday peak and the lamp peak. The **pressure drop space is larger during the midday peak**, as the non-continuous production enterprises have more adjustable flexible load resources, and the photovoltaic power generation is at a high level, while the **flexible adjustable resources are scarce during the lamp peak**, which is mostly due to the factory's night shifts, the three industries and the residents' living power load enhancement, and the renewable energy power is rapidly declining, and the **flexible load resources need to be tapped**.

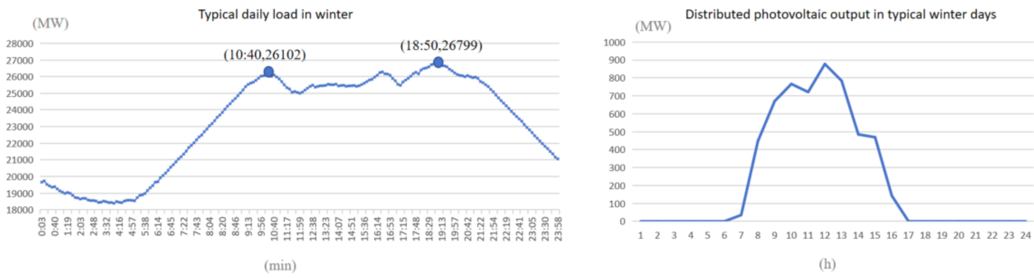


Figure X Typical daily load profile and PV output profile in winter

- **Typical industry load characteristics.** Taking the typical weekday load curve as an example, the industrial load presents **continuous production, multi-shift system, etc. The total load is large, and the multi-shift load fluctuation characteristics are obvious**. Load changes in public organizations are related to working hours, with **peaks mostly concentrated in the daytime and a high proportion of air-conditioning and lighting loads**. The load of supermarkets and catering services is related to personnel activities, with **long load duration in the evening** and a high proportion of air-conditioning load.

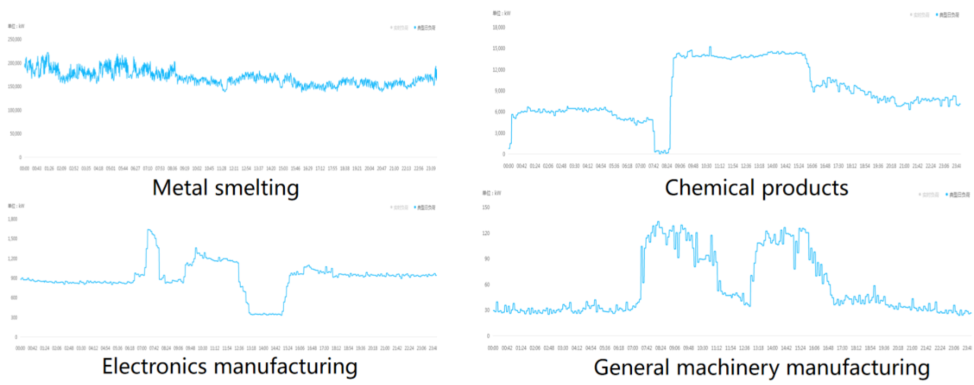


Figure XI Typical daily load profile for the industrial sector

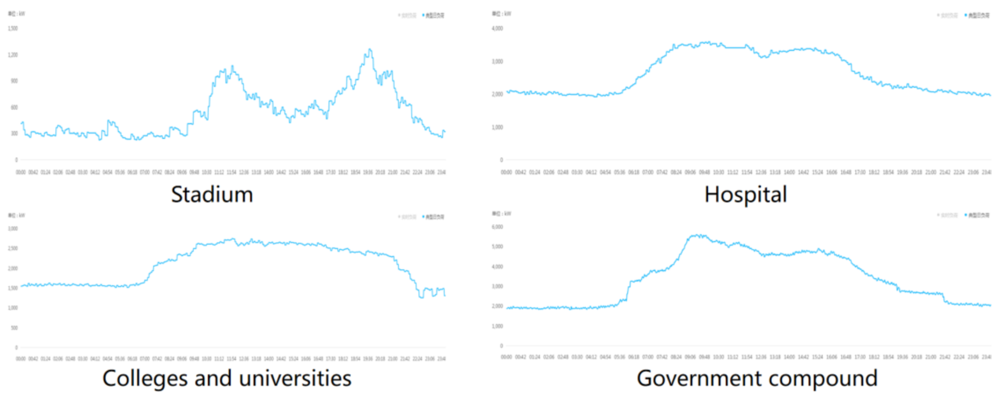


Figure XII Typical daily load profile for public institutions

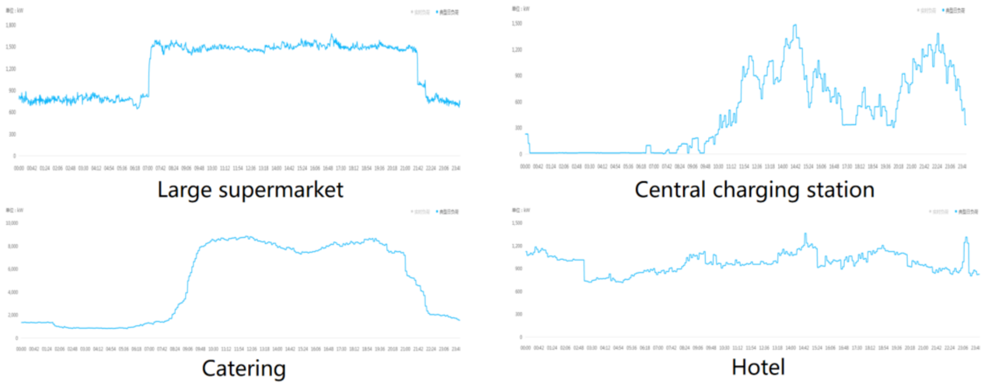


Figure XIII Typical daily load profile for supermarket, food and beverage service sector

## 3. Regional-level PEDF buildings contribute to a zero-carbon power system planning programme

- **Forecast of Suzhou's energy structure during the "14th Five-Year Plan" period. The share of coal** continues to decline, falling to around **49 per cent** in 2025. **Natural gas** demand growth is stable, accounting for about **21%** in 2025. **Oil** demand growth slows down, accounting for about **13%** in 2025. The total demand for **non-fossil** energy and its share in primary energy demand grows steadily, with oil demand peaking, natural gas demand leveling off, and the share of non-fossil energy rising to **15 per cent** in 2025.

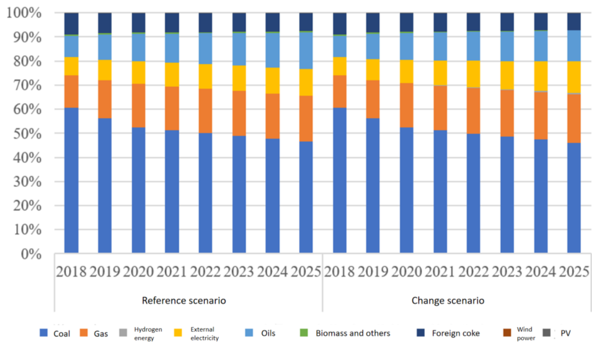


Figure XIV Primary energy structure change forecast for Suzhou in the 14th Five-Year Plan

- **Total end-use energy demand forecast.** The growth rate of total terminal energy demand in Suzhou has slowed down significantly, and will **enter the peak plateau in 2025.** Driven by the optimization of the energy use structure, the promotion of advanced energy-saving technologies and the improvement of energy service efficiency, the growth rate of total terminal energy demand in Suzhou will slow down, and total terminal energy demand will reach its peak around 2025.

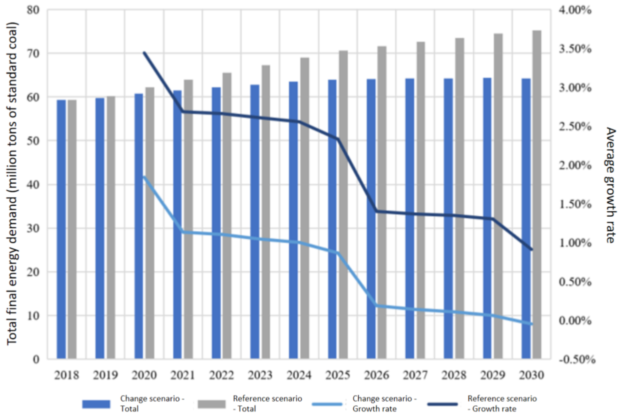


Figure XV: Trends in total end-use energy demand

- **Forecast of end-use energy demand structure. The share of electricity in the end-use energy structure of Suzhou rises the most, the share of coal declines sharply, and the share of natural gas and oil products rises slowly.** The share of electricity in the end-use energy structure rises to about 33% in 2025. The reduction and substitution of coal accelerates between 2020 and 2025, and its share in end-use energy demand falls from 22.8 per cent in 2020 to around 20.2 per cent in 2025. Natural gas consumption maintains a slow decline and oil consumption enters a peak plateau. The share of oil and gas consumption is around 24.6 per cent in 2020, rising to around 26.3 per cent in 2025.

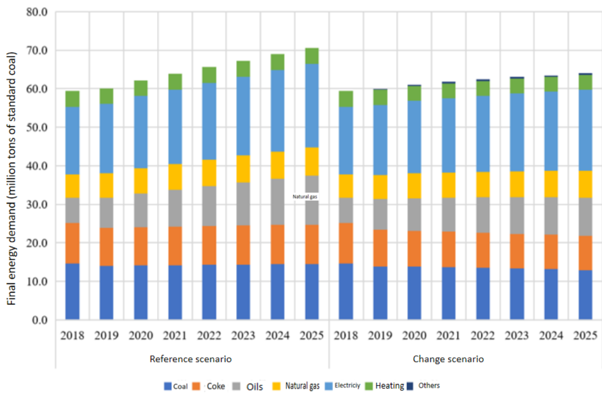


Figure XVI: Trends in the structure of end-use energy demand

- **End-use sub-sectoral energy demand.** The sectoral structure of end-use energy demand in Suzhou is slowly evolving towards equilibrium, with the building and transport sectors becoming the mainstay of growth. As the growth rate of industrial output slows down and the industrial structure and energy-using technologies are optimised and upgraded, the share of end-use energy demand in Suzhou's industrial sector declines steadily, while the share of energy used by the building and transport sectors continues to rise. Under the energy transformation scenario, the ratio of energy use in the **building, transport and industrial** sectors will be approximately 11:12:77 in 2020 and **12:16:72** in 2025.

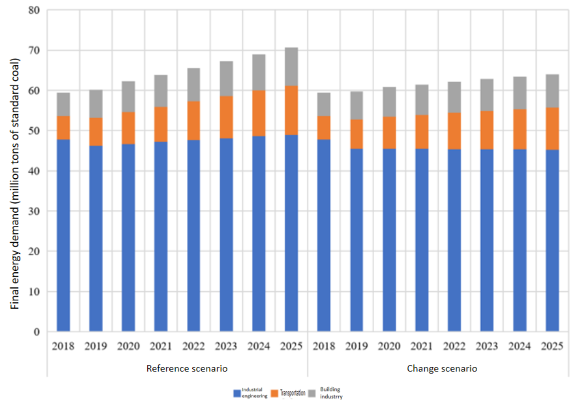


Figure XVII: Trends in total end-use energy demand by sector

- **Characteristics of the regional power system load.** Subject to the constraints of the power supply structure, the peak value of photovoltaic and comprehensive use (biogas, waste heat and pressure) power generation accounts for only **8 per cent** of the peak load, while the peak value of both external power and thermal power can reach **50 per cent** of the peak load. The scheduling basis of the regional foreign power is mainly to make the change rule similar to the overall load characteristics of the province, and the remaining part is mainly made up by thermal power units.

- **Future regional power system load forecast.** Currently, the regional power load presents **duck curve** characteristics, but due to the small proportion of new energy installed capacity, the duck shape is not obvious. In the future, with the significant increase in installed PV capacity, duck curve characteristics will be gradually highlighted in terms of the regional power system load curve in the midday. With the power to the peak and carbon to the peak, in order to maximize the use of the grid's existing distribution resources, so that the regional load and the new energy power generation time period is more in line with the regional dispatch load on the basis of the duck curve, the midday load should be more to increase, the evening load should be appropriate to reduce, resulting in the **load curve ultimately form the characteristics of the hat curve.**

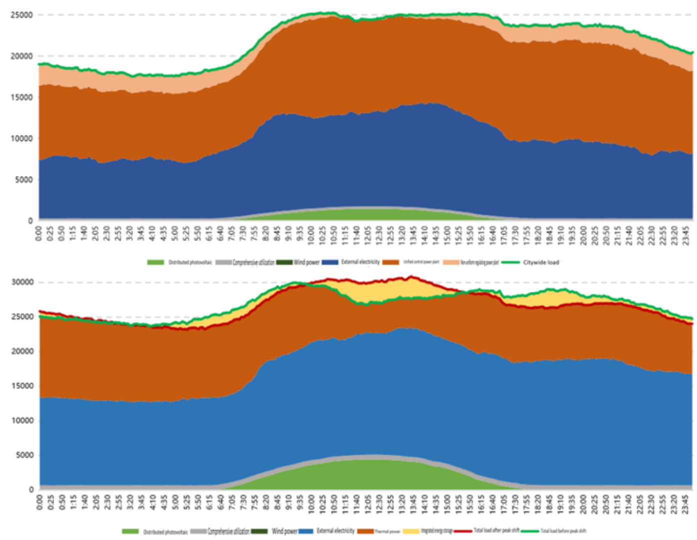


Figure XVIII "Duck curve" to "Hat curve"

- **Zero-carbon development plan for the future regional power system.** Suzhou will promote the large-scale development and utilization of new energy, promote the AC and DC hybrid upgrading of the power grid, promote the high degree of electrification of the whole society and the improvement of system-level energy efficiency, promote the application of renewable energy storage technology, accelerate the research and application of digital technology, and serve the upgrading of the electric power supporting market. Promoting the development of new energy as the installation theme, promoting the development of new energy as electricity, power main body, and realizing the whole society is the path to achieve the development of a new power system in three stages.

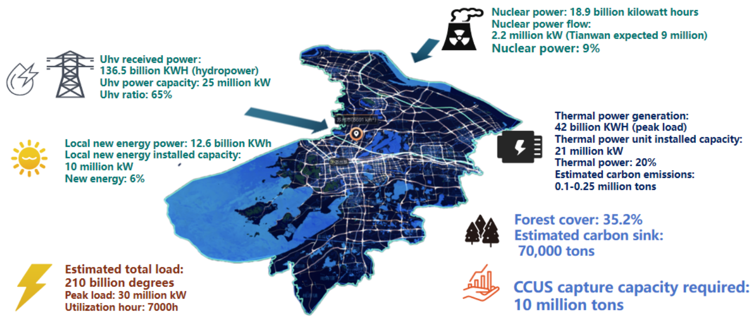


Figure XIX Zero-carbon future regional power system development plan

## 4. PEDF Project Demonstration

- **Overview of Suzhou Dongwu Gold "PEDF" Project.** The project belongs to the transformation of the old factory building, the building is planned for office, refining (wet storage) workshop, jewellery processing workshop, commercial rental, etc. The construction area of the first phase project is about 28,000 square meters, a total of three buildings. Phase I project built construction of photovoltaic in the main factory building 1 # building, restaurant 3 # building roof, and factory carport roof . Phase II project is proposed to build office 4 # building and plant 5 #, and the construction of photovoltaic on the roof.

- **PEDF System Architecture.** The first phase of the project is a demonstration of the application of the "PEDF" system, equipped with a 150kW flexible energy gateway, 441.1kWp photovoltaic, 74kW magnetic levitation chiller, 20kW DC fan coiler, and other types of DC loads, and the chiller can be flexibly controlled according to the busbar voltage.

Figure XX Aerial view of Phase I of Suzhou Gold Project

- **HVAC temperature and humidity independent control system design.** The magnetic levitation chiller unit uses 7°C water outlet, and the fresh air unit sends dry fresh air into the room to take away the indoor latent heat (humidity) load. The magnetic levitation air-cooled heat pump unit produces water at high temperature in summer and sends cooling capacity to indoor dry end as a cooling source to take away the indoor sensible heat load.

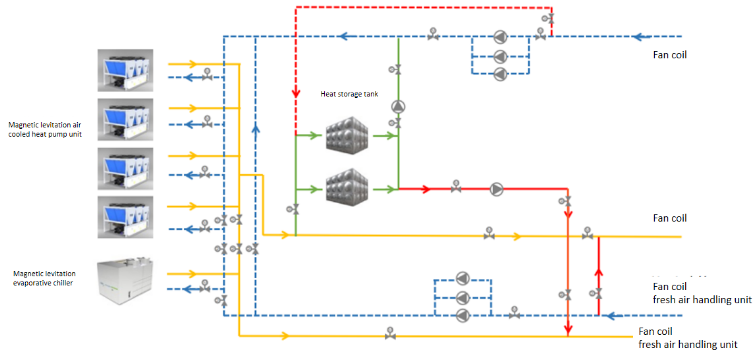


Figure XXI HVAC system sketch

- **The system operation mode is switched by season.** In the cooling season, it adopts the mode of "photovoltaic+cooling storage+DC magnetic levitation evaporative chiller cooling+other DC loads". In the transition season, it adopts the mode of "self-generation and self-consumption, with excess photovoltaic power generation inverted to the grid". In the heating season, it adopts the mode of "photovoltaic+heat storage+air-cooled heat pump heating" mode.

- **Typical operating conditions.** Main building power usage is associated with building occupant activity. In the morning at 6-7am and in the evening at 16-20pm the PV generation is weak and needs to be supplemented by utility power. Daytime PV generation is in excess when the weather is fine and excess power is returned to the external grid. On a typical workday, single day the amount of introduction of off-grid power and return of off-grid power are roughly equivalent.

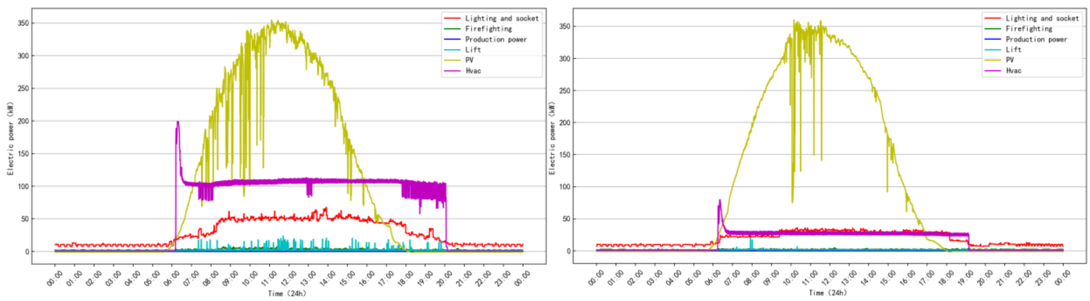


Figure XXII Typical weekday and non-weekday breakdown power curves for main building

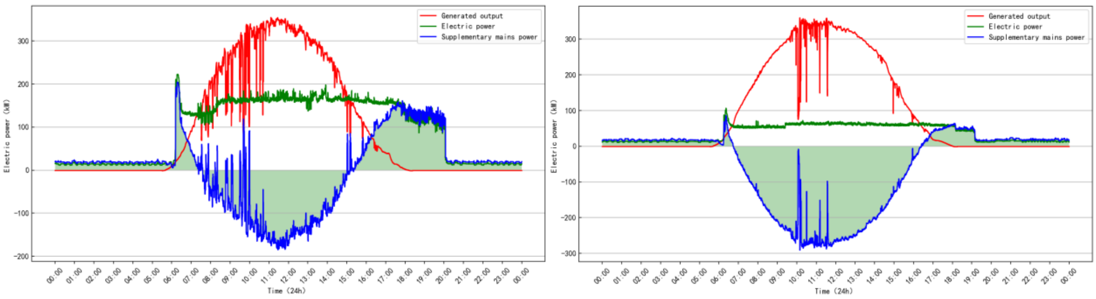


Figure XXIII Typical weekday and non-weekday utility supplemental power curves for main building

- **Electricity consumption and PV power generation on weekdays are basically the same, while electricity consumption on non-working days plummets and PV power generation is in excess.** The electricity consumption in the main building is mainly for HVAC system energy consumption, as well as office lighting and socket power, accounting for more than 80% of the total electricity consumption in the main building. Non-working day electricity consumption is reduced by 50% compared to working day electricity consumption, resulting in a large amount of PV power being sent back to the grid. It is expected to reduce chiller energy consumption in the morning and evening by switching on the heat storage tanks to reduce reliance on utility power.

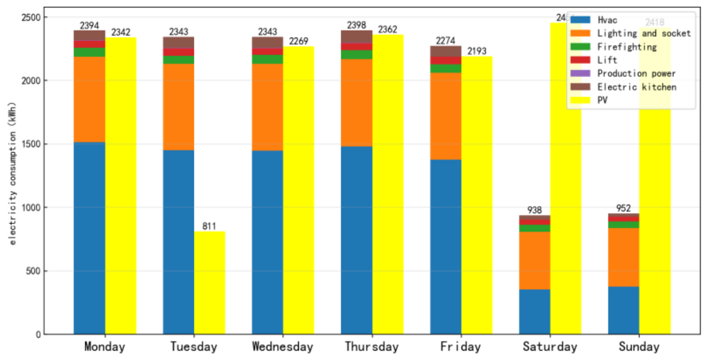


Figure XXIV Daily electricity consumption accumulation column chart for the main building

- **Demonstration of regional-level PEDF buildings synergistic linkage.** Suzhou Dongwu Gold Project is a collection of offices, refining workshops, jewellery processing workshops, R&D, office rental, restaurants, and etc, which are mixed and distributed in different buildings with complete load characteristics.

- **Cross-body clean power consumption exploration.** Since the new transformer belongs to the same household number as the old transformer, a cross-body DC bus connection can be carried out, which will provide a model reference for future power synergy and interaction at the regional level.

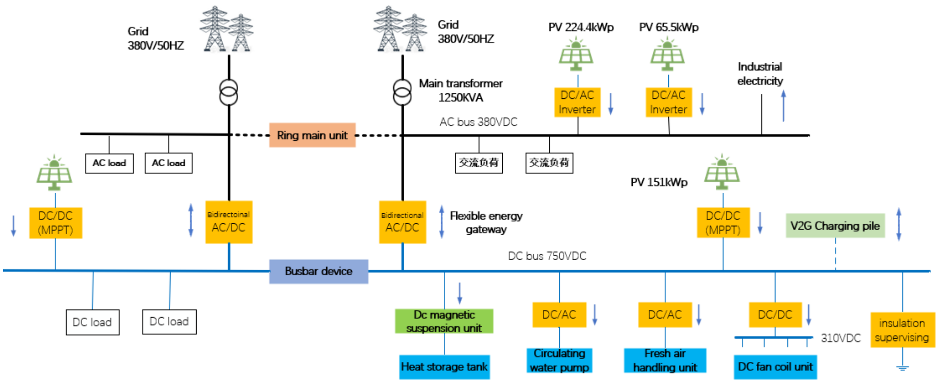


Figure XXV Cross-body clean power consumption system sketch

## 5. Conclusions and recommendations

- **The supply of clean power in the Suzhou region mainly relies on external power, and there is much room for improvement in the supply and utilization rate of local renewable energy.** It is predicted that the capacity of the Suzhou power grid to receive external power will account for about 65% of the city's maximum dispatch load, and the net power intake will account for about 50% of the whole society's electricity consumption. At present, the total amount of distributed new energy development in Suzhou is on the low side. Take photovoltaic resources as an example, only about 2 million kilowatts are being utilized at present, and with the advancement of BIPV and other technologies, about 5 million kilowatts of distributed photovoltaic resources can be utilized in Suzhou in the future.

- **In terms of power load consumption, the typical daily load curve in the region will evolve from a "duck curve" to a "hat curve" in the future, and regional flexible resources and integrated energy storage resources need to be developed.** With the continuous reduction of conventional energy units, the power supply is mainly supplied by renewable energy sources, the actual load curve can only be highly approximate to the new energy curve, the peak-valley difference and the peak-valley difference rate and other indicators need to be re-examined in the study, the regional power load regulation model is in need of a breakthrough, on the basis of the traditional peaking replication service and demand response, according to the carbon emission factor.

- **In terms of regional PEDF applications, the DC distribution system connecting photovoltaic, orderly charging of electric vehicles, centralized management of air-conditioning loads in public buildings, and the construction of distributed energy storage, etc., will take the initiative in smoothing out load peaks and transferring renewable energy power.** Typical regional power system, for example, need to equip the grid with the maximum dispatch load of about 10% of the integrated energy storage, in the policy, technology, subsidies in place and the user voluntary ideal situation, significant potential for adjustable loads exists in typical industries.