区域协同低碳发展的基础与路径

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摘 要：碳达峰碳中和既是中国高质量发展的重要目标，也是高质量发展的重要抓手。中国地域辽阔，各地区资源禀赋、经济技术水平、产业结构存在很大不同，因而碳达峰碳中和实现路径要重视区域差异化，但更要重视区域之间的协同。只有通过区域协同低碳发展才能有效缓解能源资源和绿色技术在区域分布上的供需背离矛盾，同时将碳达峰碳中和与构建新发展格局战略有机统一起来。中国区域间在长期合作竞争中形成的能源—产业关联关系以及污染治理方面的深度协作，也使区域协同低碳发展具备了深厚的历史渊源和现实基础。总体来看，应从产业结构优化、能源结构转型和绿色低碳技术创新三方面着手构建区域协同低碳发展路径，争取做到“三路并进”。不过，要保证区域协同低碳发展路径的顺利形成和长期稳定，还需要克服一系列体制机制问题。

关键词：碳达峰 碳中和 区域协调 产业结构 能源结构 绿色低碳技术

JEL 分类号：Q54, Q55, Q56, R11

碳达峰碳中和是党中央经过深思熟虑后作出的重大战略决策，是中国积极参与全球环境与气候治理的庄严承诺，体现了中国负责任大国的担当，也是中长期发展的重要框架（刘鹤，2021）。不过，中国各地区资源禀赋、经济技术水平、产业结构、生态环境承载力差异巨大，在此情形下展开碳达峰碳中和行动，不仅要强调行动方案的区域差异性，更要强调区域的协同性。中共中央、国务院《关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见》也特别指出，要“确保各地区各领域落实碳达峰、碳中和的主要目标、发展方向、重大政策、重大工程等协调一致”。

一、区域协同是低碳发展的必由之路

根据Climate Watch网站数据，中国从实现“碳达峰”到实现“碳中和”的时间要比发达国家短得多，同时还要克服能源资源禀赋、低碳技术区域分布不平衡的矛盾，这必然要求区域协同低碳发展。同时，区域协同低碳发展也是构建低碳发展的新发展格局、遵循绿色和协同的新发展理念的应有之义。而且，国务院印发的《2030年前碳达峰行动方案》也强调“各地区要结合区域重大战略、区域协调发展战略和主体功能区战略，从

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基金项目：国家自然科学基金面上项目“实现碳峰值与强度目标的区域低碳发展路径协同优化研究”（71873143）；中国社会科学院登峰战略重点学科建设项目“环境技术经济学”（sjjzdxk2017-03）。

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实际出发推进本地区绿色低碳发展”。实际上也是强调各地制定碳达峰行动方案，既要因地制宜，也要重视与其他地区的协同。

（一）能源资源和绿色技术具有突出的区域分布供需背离矛盾

中国存在突出的能源资源区域分布供需背离特征。从能源禀赋来看，中国的能源结构以煤为主，石油和天然气资源储量相对不足，煤炭资源又主要分布在西部和华北地区；可再生能源以水力资源为主，而水力资源又主要分布在西南地区。除煤炭和水电外，中国的新能源资源也主要分布在西部地区，其中西部地区拥有全国78%的风能资源技术开发量，88.4%的光伏资源技术开发量（韦福雷，2021）。中国的主要能源消费地区则是经济发达的东部沿海地区。上述能源区域分布供需背离特征，导致中国呈现“大规模、长距离的北煤南运、北油南运、西气东输、西电东送，是中国能源流向的显著特征和能源运输的基本格局”[1]。

同时，中国的绿色技术在区域分布上也呈现明显的供需背离特征。绿色技术专利的数量和质量能在很大程度上反映了一个地区的绿色技术水平。从中国国家知识产权局专利数据库中的绿色技术专利数据来看，中国各地区的绿色技术水平都在不断上升，但呈现明显的东中西部地区逐次递减特征；同时绿色技术水平较高的城市都是经济发达且行政级别较高的大城市（孙博文、张友国，2022）。有色金属、电力、钢铁、水泥等高耗能行业的能源技术水平总体也呈现由东向西递减特征，而且能源技术的地区差异没有呈现收敛趋势，这意味着能源技术区域扩散效应不明显（吴滨，2009）。然而，绿色技术水平相对较低的中西部地区和数量众多的中小城市，却是最迫切需要通过先进绿色技术提升碳排放效率的地区，这些地区的绿色技术则难以满足其需求。上述原因造就了中国绿色技术区域分布的供需背离突出特征。

显然，无论是能源资源还是绿色技术的区域分布都呈现明显的供需背离矛盾，要解决这些矛盾需要区域间加强协同。东部沿海经济发达地区需要中西部地区提供大量的能源，而中西部地区需要东部地区的绿色技术以改善能源效率和发展清洁能源。

（二）低碳发展水平存在明显的区域不平衡

自改革开放以来，为促进生产力发展，中国总体上采取了不平衡发展的战略，使更具经济优势的东部沿海地区先行发展起来，导致中西部地区与东部地区的发展差距不断扩大。在这一过程中，东部沿海地区积极发挥其人力资源、经济基础、公共基础设施、区位等方面的优势，充分利用国家给予的投资、财税、外资外贸、金融等方面的优惠政策，快速推进市场经济体制建设，率先接触、采用、开发新技术，使其经济迅速发展起来，也造成区域间经济乃至技术水平的不平衡。国家统计局的数据表明，虽然在20世纪90年代末期便开始实施西部大开发战略，其后又相继实施了东北振兴、中部崛起等力促区域发展平衡的战略，但由于交通、人才等各方面因素的制约，中西部地区以及东北地区的人均GDP仍与东部地区有较大差距。

与此同时，得益于较高的技术水平及产业结构的不断转型升级，东部沿海地区的低碳发展水平也远高于

[1] 资料来源：中华人民共和国国务院新闻办公室，《中国的能源状况与政策（白皮书）》，http://www.nea.gov.cn/2011-08/22/c_131065968.htm，2007-12。

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内陆地区。一方面，如前所述，虽然各地区的绿色低碳技术水平都在不断进步，但总体上东部地区的水平要仍明显高于其他地区。另一方面，近年来，特别是党的十八大以来，随着绿色低碳发展战略的实施、“双碳”目标的提出，我国整体的产业结构逐步向低碳化调整，但区域间低碳化水平存在差异，不同省市间产业结构低碳化效应不尽相同。有的省份产业结构调整持续有利于碳的减排（北京、浙江），但调整速度有快有慢，而有的省份产业结构调整的碳减排效应还不明朗（张友国、白羽洁，2021）。

在区域经济发展、技术水平、产业结构等存在较大差异的情况下，要在既定且较短的时间内实现“双碳”目标，尤其是经济发展有障碍且本身产业布局又不具低碳优势的地区，更是难上加难，所以不仅在经济发展上需要先发展带动后发展，而且在绿色低碳发展方面也同样需先接近低碳的地区发挥带动作用。低碳发展先进地区应将其低碳发展的优势和条件，辐射到周围地区，带动周边地区的低碳发展。

（三）构建新发展格局要求区域协同低碳发展

构建新发展格局与碳达峰碳中和这两大战略具有高度一致性。一方面，构建新发展格局与碳达峰碳中和在推动高质量发展这一目标上具有高度一致性。碳达峰碳中和既是高质量发展的主要目标之一，又是促进高质量发展的重要抓手，而构建新发展格局是推动高质量发展、实现“十四五”规划和2035年远景目标的主攻方向。另一方面，构建新发展格局与碳达峰碳中和都要遵循新发展理念。中国要构建的新发展格局是国内大循环为主体、国际国内双循环相互促进的新发展格局，其关键在于经济循环的畅通无阻，这对区域协调发展提出了更高的要求。除了高度强调协调发展外，构建新发展格局也必须遵循其他新发展理念，蕴含于绿色发展理念的低碳发展必然也是构建新发展格局的应有之意。实现“碳达峰碳中和”的双碳目标，自然也要高度重视贯彻落实协调发展理念，在新发展格局中同时打通经济发展与环境保护矛盾点。

从国内大循环视角来看，区域协同低碳发展是构建新发展格局与碳达峰碳中和高度融合的需要，更是绿色和协同发展理念的综合体现。一方面，区域协同低碳发展，要求各区域中各经济主体在碳达峰碳中和框架下相互配合与有机协作，这有利于有限的生态环境容量和资源承载力在空间配置上得到更好的优化，从而在资源禀赋总量有限且区域差异明显的条件下，保证各区域经济发展的顺利实现。另一方面，区域协同低碳发展不仅有助于改善生态环境质量，也将催生出大量有益于人民身心健康的绿色、健康、安全的产品和服务，如生态有机食物、无害洗涤用品、节能环保厨具、新能源汽车、生态旅游服务等，从而有效扩大内需。而扩大内需正是构建新发展格局的战略基点。因此，推动区域协同低碳发展也是构建新发展格局的重要途径。

从国际国内双循环相互促进的视角来看，区域协同低碳发展也是推动新发展格局形成的重要途径。在气候变化越来越受国际社会重视的大趋势下，根据《巴黎协定》，绿色低碳发展已经成为国际合作的重要原则。新发展格局要求更高水平的对外开放，更好地利用国际国内两个市场、两种资源。坚持低碳发展显然有助于为中国与国际社会深度合作打下坚实的基础，有利于中国吸引更加高端的国外资源要素流入以助推国内大循环，从而也有利于优化贸易结构并促进中国的高水平对外开放。对外开放又是各个区域各经济主体共同参与的发展战略，而区域协同能够调动区域内外资源超强联动，综合利用内外部资源并发挥超强效用，因而是高水平对外开放的必然要求。因此，区域协同低碳发展将十分有助于促进高水平对外开放，继而推动构建新发展格局。

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二、区域协同低碳发展的历史渊源与现实基础

区域协同低碳发展具有长久的历史渊源和坚实的现实基础。一方面，如前所述，中国特殊的能源供需区域格局以及其他资源禀赋的区域差异性，使各区域间早已形成密切的能源—产业关联关系，而区域协同低碳发展可视为区域间能源—产业关联的升级或更高要求。另一方面，中国近年来在污染防治领域实施的一系列区域协同治理措施，为区域协同低碳发展积累了宝贵的经验。

（一）长期发展中形成密切的区域间能源—产业关联

无论是在计划经济时期还是改革开放以来，中国区域间始终保持着密切的经济关联。首先，区域间有着密切的直接能源关联性。由于中国的能源资源区域分布存在突出的供需背离矛盾，为了促进能源资源配置的优化，中国实施了西气东输、西电东送、西煤东运、北煤南运等国家重大能源战略，投入巨资兴建了相关基础设施，如三峡工程、西气东输管道、西电东送电网系统、煤炭运输交通体系。大量的能源直接从能源富集地区直接调往东部沿海经济发达地区，以满足其能源消费需求。例如，2021年，西气东输工程年输气量突破了1000亿立方米，截至2021年12月，西气东输工程累计输送天然气7000亿立方米，覆盖了我国西部、长三角、珠三角和华中等地区的400多座城市、3000余家大中型企业，惠及近5亿人[2]。

其次，区域间有着密切的产业关联性。中国不仅能源资源的区域分布不均衡，其他很多重要资源的分布也是如此。同时，各地区经过长期发展逐渐形成了本地区的支柱产业和优势产业，区域间有较强的经济互补性。这些原因导致中国区域间产业关联密切，区域间贸易规模巨大。例如，根据2017年北京市地区投入产出表（国家统计局国民经济核算司，2020）的价值量数据，北京市的中间投入品中，有45%是从其他地区调入的产品或服务，这些调入中间投入品占北京市总产出的29%；其他地区从北京市调出的中间投入品价值量占北京市总产出的17%；北京市的煤炭、石油和天然气更是完全需要从外地调入。

最后，区域间密切的产业关联产生了规模巨大的区域间碳排放转移。因为各种产品或服务的提供都需要消耗能源并产生碳排放，购入产品或服务就相当于将相应的碳排放转移到该地区，这就是区域间碳排放转移。由于中国区域间贸易规模较大，由此形成的区域间碳排放转移量不容小觑。根据张友国（2018）的计算结果，由于区域间碳排放转移量巨大，导致各地区按生产原则和消费者原则承担的碳排放责任差异较大；其中，由于通过区域间贸易转移出去大量的碳排放，浙江、上海和北京等几个地区的碳排放消费责任比其碳排放生产责任高60%~190%。

（二）区域协同污染治理的显著成效和宝贵经验

近年来，中国为提升生态环境质量而不断强化环境治理体系和治理能力的现代化，其中在大气污染治理方面所采取的区域间联防联控措施取得了很好的成效，为区域协同低碳发展提供了借鉴、积累了宝贵经验（黄润秋，2022）。

[2] 资料来源：人民网，http://finance.people.com.cn/n1/2021/1228/c1004-32319228.html。

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一方面，重视协同治理机制的顶层设计和自上而下的周密部署。2010年国务院从防治重点区域、重点污染物、防治的手段（产业结构调整、能源清洁利用、完善区域空气质量监管体系等）对大气污染防治工作进行了部署。认识到大气污染的治理，特别是区域性大气污染治理，需要区域间的协同推进。2015年9月11日，中共中央、国务院印发的《生态文明体制改革总体方案》指出，建立污染防治区域联动机制，完善京津冀、长三角、珠三角等重点区域大气污染防治联防联控协作机制；《中华人民共和国国民经济和社会发展第十四个五年规划和二〇三五年远景目标纲要》中进一步强调坚持源头防治、综合施策、强化多污染源协同控制和区域协同治理。

另一方面，以大型活动为契机，积极探索大气污染治理联防联控措施。例如，为保障2008年“绿色奥运”，华北六省（市）首次打破行政界限签署环境保护合作协议，实施区域协同、省际及部门联动，全面开展大气污染综合控制，确保奥运期间北京空气质量明显优于往年同期水平。2014年北京APEC会议期间使用了最严苛的超常规的手段（机动车限行与管控、燃煤和工业企业停限产工地停工、调休放假），从而在会议期间使北京的天空呈现了久违的“北京蓝”。2015年北京“九三”阅兵、2016年杭州G20峰会等一系列活动中，相关地区和部门也重点针对联防联控范围、精准控制、浓度削峰、联动方式等进行了探索，使我国的大气污染防控在科学认识和防控能力上收获了宝贵经验。

实践效果也表明，区域联防联控与协同减排是遏制区域性大气污染的根本出路。2019年3月9日联合国环境规划署发布《北京二十年大气污染治理历程与展望》评估报告，其中强调北京市在五年内实现了国内外普遍认为难以完成的目标，2017年的PM2.5年均浓度比2013年下降35.6%。据不完全统计，2015~2020年，全国重污染天数降幅超50%，其中京津冀及周边地区重污染天数比例降低约6%（燕丽等，2018）。得益于周边地区的共同努力，2013年北京主办APEC会议期间出现的“北京蓝”，现在也几乎成为北京空气质量的“新常态”。这也进一步印证了区域协同降碳的必要性和有效性。

三、区域协同低碳发展的可行路径

低碳发展一要靠经济结构的持续低碳化转型，二要靠不断推进绿色低碳技术创新。其中经济结构的低碳化转型主要包括两方面，一是产业结构的低碳转型，二是能源结构的低碳转型。因而，区域协同低碳发展的路径大体上可以从协同推进产业结构低碳转型、能源结构低碳转型、绿色低碳技术创新三个方面加以考虑。

（一）区域协同推进产业结构低碳转型

区域协同推进产业结构低碳转型就是要在碳约束下，通过充分发挥各区域的比较优势，使要素在更大空间范围得到优化组合，使产业在空间布局上得到优化。从理论和实践来看，区域协同推进产业结构优化的路径包括区域间产业转移、产业融合发展等不同类型，不同类型下的协同方式又有多样性。区域协同推进产业结构低碳转型也可以采取上述方式，但要突出碳减排与经济发展的协调。

一方面，对于国民经济发展离不开的高耗能产业，适宜通过产业转移向能源富集地区集聚。例如，可以考虑将东部地区高耗能低耗水的产业转移到西北能源富集地区（潘家华等，2021），这样即避免了能源长途输送

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带来的损失，又能较好地发挥西北能源富集地区的比较优势，带动西北地区经济发展。又如，西南地区的贵州省，其在长江经济带中的优势行业主要集中在煤炭开采和洗选业，可考虑通过承接产业转移，在巩固突出优势的同时，努力提升煤化工及其深加工以及电力、热力的生产和供应业优势（张友国，2020）。在具体产业转移方式上则可根据情况灵活而定，通过企业整体搬迁、共建专业产业园区、打造飞地经济、产业链整体转移、关联产业同步转移等实现。

另一方面，区域间可以通过产业融合发展，协同促进低碳型高附加值产业，实现产业结构低碳转型。其一，通过产业集聚实现产业结构低碳转型的区域协同。例如，在长江经济带中，长三角地区具有发展高附加值先进制造业的比较优势，上海可致力于将其自身打造成全球性科技创新中心，江苏和浙江可以积极发展上海支柱产业的配套产业，从而在整个长三角地区实现先进制造业集聚发展，继而推动整个地区产业结构不断优化升级和绿色低碳发展。由于土地限制，长三角地区又可将先进制造业之外的其他技术密集型产业向长江中、上游地区转移，以带动整个长江经济带的产业结构低碳转型。

其二，区域间还可以通过联合打造形成具有技术先进、高附加值、低碳化特点的高端产业链，实现跨区域产业结构低碳转型。对于新兴产业如先进制造业，相邻地区可以充分发挥各区域的比较优势，采取区域协同打造产业链的方式实现融合发展，避免低水平重复建设和恶性竞争。例如，京津冀地区目前正积极协同打造氢能产业链，其中北京将发挥技术创新中心、金融中心和国际交流中心的作用，为产业链发展创造相应的技术、金融和市场条件，并聚焦氢能高端整车制造；天津和河北则聚焦氢能供给、储运所需特种材料和设备的研发与供应（张友国、白羽洁，2021）。

（二）区域协同推进能源结构低碳转型

区域协同推进能源结构低碳转型在中国其实已有很长的历史。西气东输工程的建成运行，使工程沿线地区实现了天然气对其他化石能源特别是煤炭的大规模替代，从而使沿线地区的能源消费结构得到了整体优化。西电东送工程将西部地区的煤电和水电源源不断地输送到东部地区，既减轻了煤炭运输压力和沿途环境污染，又使东部地区节约了大量的发电用煤，能源结构得到极大优化。

不过，上述重大能源战略工程仍然只是起到了局部优化能源结构的作用，要在全国范围内使能源结构得到明显优化，还需要区域间进一步的协同合作。西气东输和西电东送虽然有效促进了东部地区能源结构优化，但似乎没有对西部地区能源结构优化产生明显影响，使其在全国范围内对能源结构的优化作用大打折扣。这就需要进一步考虑西部地区的能源结构优化问题。如前所述，中国的新能源资源也主要分布在西部地区，因而不断将这些新能源资源开发出来，替代以煤为主的化石能源，这将是优化西部地区乃至全国能源结构的必由之路。东部地区通过资金、技术、人才、培训等多种方式帮助西部地区将储量巨大的新能源资源开发出来，则是未来区域协同推进能源结构低碳转型的主要途径。与此同时，东部地区也应因地制宜，通过“多能互补系统集成优化工程”和“互联网+智慧能源工程”建设，进一步加大风电、光伏、生物质能源等新能源发展力度，构建相应的分布式能源系统，从而部分缓解西部地区的煤电压力，优化西部地区的能源结构。

还要强调的是，西部地区的能源结构优化一定要循序渐进，从国家的高度考虑本地区的能源结构优化。

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如果西部地区仅从本地的能源需求出发，那西部地区完全可以大规模削减煤电发电，从而降低煤炭在能源消费中的份额，但这样会给东部地区的经济社会发展造成冲击。这是因为东部地区对西部地区仍有较大的能源依赖性，特别是对西部煤电的依赖程度仍然很高。在新能源大规模投入使用之前，西部地区还需要向东部地区稳定地提供煤电，以保障东部地区经济社会正常运行，而不至于出现“拉闸限电”等影响社会民生的事件。这也是区域系统推进能源结构优化需要特别重视的问题。

（三）区域协同推进绿色低碳技术创新

其一，针对绿色低碳技术关键技术、设备和零部件开展跨区域产学研一体化联合攻关。当前，中国的绿色低碳技术水平在不少领域，特别是在零碳负碳技术领域（如新能源技术），与国际先进水平还有较大差距，一些关键设备和零部件还受制于人（张友国，2021），因此绿色低碳技术区域协同创新，重点要在绿色低碳技术的短板和瓶颈环节加强区域联合攻关。具体合作形式可以是区域间科研机构或高校的合作研究、企业间联合研发、科研机构或高校与企业的产学研一体化联合攻关。其中，要特别重视充分发挥企业在绿色低碳技术创新中的主体作用，因而产学研一体化联合攻关模式是未来绿色低碳技术区域协同创新的趋势。例如，作为中国绿色低碳技术创新的一项重大成果，“二氧化碳（CO_2）循环发电试验机组”的研制就采用了跨区域产学研一体化联合攻关模式，该机组就是由中国华能集团下属的西安热工院牵头组建创新团队，联合国内顶级高等院校、科研院所、设计单位、制造企业和工程建设单位等创新链、产业链上下游30余家机构开展集智攻关而成[3]。区域协同绿色低碳技术创新模式还可用于推动超临界二氧化碳循环发电技术在高效光热、电热储能、先进核电和灵活火电等领域的研发与应用。

其二，通过区域协作，运用先进技术手段对跨区域产业链的碳排放进行监控和管理，以提升跨区域产业链的碳排放效率。各地可先建设基本覆盖地方主要用能单位的低碳节能智慧管理系统，并在此基础上强化区域内对重点行业的运行监测，建立完善产业链供应链苗头性问题预警机制，加强问题分析研判，积极应对突发情况，及时处置潜在风险。例如，成渝地区提出了通过大数据技术协同控制产业链碳排放的设想。成渝地区紧邻具有“大数据”优势的贵州省，可以考虑与贵州省加强交流，协同推进大数据发展，先行探索试验区域内产业链的碳排放监测与控制。[4]

其三，打造绿色创新共同体。绿色创新是区域协同低碳发展的重要支撑，因各区域的绿色创新比较优势存在差异，因而可以考虑依据“中心—外围”的发展模式（Krugman，1991），打造绿色创新共同体。例如，“上海+长三角”区域绿色创新共同体模式值得借鉴。作为长三角绿色创新的领头羊角色，上海正致力于建设具有全球影响力的科创中心，其在绿色创新领域具有较强的基础，通过产业带动、技术带动、平台带动、制度带动、载体带动，在长三角绿色科技创新共同体建设中发挥着引领带动作用。2017年12月，绿色技术银行总部落户上海，绿色技术银行管理中心在沪揭牌，创设35亿元绿色技术成果转化基金，使得这一系统内具备了技术创

[3] 资料来源：中国电力新闻网，我国首座大型二氧化碳循环发电机组投运，http://www.cpnn.com.cn/news/kj/202112/t20211213_1465222.html。

[4] 资料来源：重庆市发展和改革委员会，成渝地区双城经济圈碳达峰碳中和联合行动方案（征求意见稿），http://fzggw.cq.gov.cn/hdjl/yjzq/202111/t20211119_9996222_wap.html。

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新及成果转化的资金条件(周冯琦、胡静,2020)。

要说明的是,区域协同低碳发展的三个主要路径并不是相互独立的,它们之间具有很高的融合性,往往是“两路并进”或“三路并进”。例如,北京市消费的电力主要是内蒙古提供的煤电,北京与内蒙古开展新能源与可再生能源科技合作(杨永平,2009),就不仅是两地在绿色低碳技术创新方面的协同,也是两地在能源结构转型方面的协同。

四、区域协同低碳发展要加强体制机制建设

区域协同低碳发展的路径主要可从碳约束下的产业结构优化、能源结构转型、绿色低碳技术创新三方面进行探索和设计,但上述三方面的区域协同路径的形成还面临一些体制机制和政策问题,既包括现有体制机制形成的阻力问题,也包括相关体制机制或政策缺失造成的激励不足问题。这些问题的解决将加快区域协同低碳发展路径的形成,并有助于这些路径在长期内保持稳定。

(一)区域协同推进产业结构优化面临的体制机制问题与对策

区域协同推进产业结构优化面临的体制机制障碍主要来自利益分配机制,财税体制就是其中起决定性影响的利益分配机制。

中国1994年的分税制改革(财政分权)顺应了市场经济体制的需要,对各地发展经济起到了很好的激励作用,但也在一定程度上影响了区域间通过协同优化产业结构来实现碳减排。与财政分权密切相关的政绩考核制度和事权划分制度进一步强化了上述影响。

其一,影响了部分东部地区将高耗能企业向西部地区迁移的积极性。不少地区为了留住企业获得相应的税收分成,不愿将企业迁出。以GDP为核心的政绩考核体系,也导致一些地区担心影响本地GDP而不愿迁出相关企业。[5]从解决就业问题出发,一些地区也不愿企业从本地迁出(江洪,2009)。不少能源密集型企业在东部一些地区具有创造税收、维持GDP和解决就业的重要作用,其中一些地区因上述原因而不想轻易将这些企业迁出。

其二,容易造成区域间项目投资同质化。在上述体制机制下,各地为了获取短期经济社会效益,可能会同时在一些短期见效快的项目上进行投资,从而导致低水平重复建设、地方保护主义和恶性竞争现象,影响不同地区在产业结构优化方面的协同发力,并妨碍国家整体经济结构的低碳转型。特别是当那些项目还具有碳密集型特征时,区域协同低碳发展会受到更大的冲击。

此外,一些西部能源富集地区还存在市场体制不完善、政府部门服务业意识不强、产业配套条件薄弱、交通不便、远离市场等诸多短板,也导致相应企业不愿迁入这些地区。同时,以企业注册地而不是税源地为标准缴纳企业所得税的征税制度,也影响了一些中西部地区转入相关企业的积极性,因为无法正常获得税收,还得为企业做好各种服务工作。

[5] 资料来源:中国国际经济交流中心,全面实施差别化改革措施释放东、中、西部产业梯度,http://www.cciee.org.cn/Detail.aspx?newsId=12918&TId=495,2014-05-30。

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针对上述体制机制问题，首先，应加强对地方政府的低碳发展绩效考核，使低碳发展内化为其决策的重要约束，同时在能耗双控指标以及未来将推出的双碳约束指标方面，收紧东部地区的指标额度，而适当增加西部地区的指标额度。其次，要以构建新发展格局为契机，通过深化市场经济体制改革和行政管理体制改革，进一步打破地方行政壁垒，推进市场一体化，使市场在更大的空间发挥优化资源配置的作用，从而提高大区域乃至全国的资源利用效率和碳排放效率。其三，各地区特别是相邻地区应在碳约束下做好产业规划上加强协同对接，与京津冀协同发展、长江经济带发展、粤港澳大湾区建设、长三角一体化发展、黄河流域生态保护和高质量发展等国家重大区域发展战略相结合，充分发挥本地比较优势、找准自身特色，从而促进地区产业合理分工，提升协同减碳效应。其四，应鼓励不同地区的经济开发区或产业园区之间依托产业链加强合作、分工，实现跨区域资源配置优化，提升跨区域产业链的竞争力和碳排放效率。其五，积极发展跨区域行业协会或类似合作机构与平台，加强产业链上企业间的对话、企业与政府间的对话，统筹整个行业的低碳发展。其六，中西部能源资源富集地区应进一步优化营商环境，加强相关基础设施建设，为承接高附加值的能源密集型产业转移作更充分的准备。

（二）区域协同推进能源结构转型面临的体制机制难题与对策

体制机制问题是中国能源结构转型的主要障碍（朱敏，2015），当然也是区域协同推进能源结构转型的主要障碍。能源结构转型的关键在于新能源的发展，而新能源发展面临的体制机制问题包括市场准入不顺畅和激励机制不完善两方面。能源结构转型中不利于区域协同的主要体制机制问题则是全国统一电力市场体系尚未建立起来。

新能源市场准入不顺畅。新能源市场准入方面的体制机制问题主要是并入电网难、行政审批难。新能源接入电网不仅需要经过较长的审批流程，而且在入网过程中为了保证电网安全性而投入的建设成本较大（秦海岩，2020）。特别是在电力供应充裕时，部分地方政府还通过行政手段保证本地煤电机组发电，对消纳区域外的新能源电力没有积极性（李琛奇、陈发明，2018）。行政审批方面的主要难题是，新能源项目审批涉及土地、林业、电力、环保等多个部门，管理环节多，审批权重叠、多头管理、重复管理现象严重，批复周期长、手续繁杂、费用高（朱敏，2015；秦海岩，2020）。

新能源发展的激励机制不健全。新能源发展面临的激励机制问题主要来自土地约束、电价、财政补贴发放、金融支持等几个方面。由于过去几十年经济发展中大规模的土地已经被占用，当前国土空间规划又日趋严格，全国各地的土地资源都已经越来越稀缺，新能源的发展也严重受限于土地制约。电价方面的问题主要是新能源的消纳成本不能有效计入电价，从而影响了电网消纳新能源的积极性。财政补贴发放问题主要是对新能源企业的财政补贴不能及时到位，通常都要经过差不多两年时间才能真正进入新能源企业账户。金融支持方面，新能源行业是一个资金密集型行业，所需资金规模大、风险高，因而一直面临融资难问题。

全国统一电力市场尚未完全建立。电力市场建设是近年来中国电力系统改革的核心内容[6]，其实施步骤和目标是：先试点建立省级电力市场和跨省的区域性电力市场，完善跨省跨区电力市场交易机制，继而建立

[6] 资料来源：中共中央、国务院印发《关于进一步深化电力体制改革的若干意见》（中发〔2015〕9号）。

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全国统一电力市场。目前省级电力市场和跨省的区域性电力市场建设已经取得一定成效并积累了宝贵的建设经验，但全国统计电力市场尚未完全建立，影响了部分区域富余电力在全国范围内的合理配置，不利于区域协同推进能源结构转型。

针对上述主要问题，首先，应当积极探索围绕新能源的电力市场体制建设（史丹，2018）；进一步强化对新能源市场准入的法律保障，以此削弱不利于新能源发展的行政干预；将新能源项目审批制逐步过渡到核准制。其次，应当在土地资源方面加大对新能源项目的倾斜力度；使终端电价充分体现新能源接入电网的消纳成本（郭剑波，2021）；完善对新能源项目的财政补贴发放制度；大力发展绿色金融以满足新能源发展所需的大规模资金需求；严格按照2021年中央经济工作会议精神，不再将新能源消费纳入能源双控范围；在全国碳排放权交易中，可考虑电力企业与新能源消纳相关的碳排放不占其碳配额指标。其三，贯彻落实好《关于加快建设全国统一电力市场体系的指导意见》[7]，尽快建成包含多个区域层次、交易规制和技术标准规范统一的全国统一电力市场体系，夯实区域协同推进能源结构转型的基础。

（三）区域协同推进绿色低碳技术创新面临的体制机制难题与对策

绿色低碳技术创新具有“双重外部性”特征，即绿色低碳技术创新首先在推动技术进步上具有正的外部性，同时在改善环境质量方面具有正的外部性。因而，区域系统推进绿色低碳技术创新不仅面临着与其他技术创新同样的体制机制难题，还面临着其自身独特的体制机制难题。

一是解决资金保障机制问题。由于创新是一项高风险商业活动，因而除了风险投资基金外，不容易获得其他资金支持，而风险投资往往又难以满足创新的资金需求。对于绿色低碳技术创新而言，这一问题更加突出，因为绿色低碳技术创新主要目的是解决环境问题，在环境规制不是很严格的情况下，其经济效益很难吸引资金投入。因此，要通过设立区域协同绿色创新基金、放宽债券市场限制、鼓励风险投资、知识产权质押、保险补贴等方式，特别是通过大力发展绿色金融，解决绿色低碳技术区域协同创新面临的资金保障机制问题。

二是解决人才跨区域流动机制问题。目前，绿色低碳技术区域协同创新方面还存在妨碍人才在区域间流动的资格认证、社会保障、公共服务等诸多问题。要通过构建跨区域的人才数据库，采用统一的、科学合理的人才评价体系，实行技术资格和职业资格跨区域通行制度，逐步使绿色低碳技术人才能够跨区域无障碍享受其在社会保障、公共服务方面的相关权益。

三是建立健全跨区域的市场化利益分享和风险共担机制。目前在绿色低碳技术协同创新方面，区域间还缺乏较为完善的利益分享和风险共担机制，导致区域间相互学习借鉴多、实质性合作少，各自为战现象突出。其中一个重要原因是企业还没有真正成为绿色低碳技术创新的主体，以政府投入研发资金为主的创新模式不易形成市场化的利益分享和风险共担机制。因此，要根据《关于构建市场导向的绿色技术创新体系的指导意见》（发改环资〔2019〕689号），强化企业在绿色低碳技术创新的主体地位，依托企业加快建立“产学研金介”深度融合的区域间市场化的利益分享和风险共担机制。

四是加快建设多层次的全国绿色低碳技术交易市场。绿色低碳技术创新区域分布不平衡，绿色低碳技

[7] 2021年11月24日中央全面深化改革委员会第二十二次会议审议通过。

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术创新能力较强地区的辐射力也很有限，其中一个重要原因就是缺乏一个完善的全国绿色低碳技术交易市场体系，使绿色低碳技术创新供需不能及时匹配。应鼓励区域合作共建跨区域规范运行的绿色低碳技术交易市场，积极培育相关中介服务机构和专业“经纪人”队伍，并在此基础上形成全国性绿色低碳技术交易市场。

五是解决好法律保障问题。虽然我国对知识产权的保护制度不断完善，但在绿色低碳技术知识产权保护方面仍存在一些亟待解决的问题，如成果转化的利益分享问题、相关权益资本的利益保障问题等。同时，在环境法规方面也存在执法不严的问题，不利于为绿色低碳技术创新提供外部激励。这些问题的解决有待于相关法律法规的逐步完善。此外，区域间还应通过工作通报、联合执法、建立例会制度等对接联动机制协同加强知识产权保护。

五、结论

碳达峰碳中和已经成为中国发展的重要约束，“全国统筹”是实现碳达峰碳中和目标必须坚持的原则，这一原则不仅意味着要根据各区域实际情况分类施策，更意味着各区域应协同施策。中国能源资源和绿色低碳技术在区域分布上的供需背离突出特征，区域间长期以来形成的深刻经济社会关联关系以及构建新发展格局的要求，使区域协同低碳发展成为碳达峰碳中和工作的必然选择和可行选择。从碳排放的关键影响因素入手，区域协同低碳发展应主要做好产业结构优化升级的区域协同、能源结构转型的区域协同以及绿色低碳技术创新的区域协同三方面的工作，与之相适应的体制机制也应尽快建立起来。本文对区域协同低碳发展路径只是进行了初步探讨，对这一问题的研究还亟待深化。

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Pathways of Regionally Coordinated Low-Carbon Development in China

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Abstract: *Carbon peak and carbon neutrality are both important goals in the Chinese government's plans for future economic development. With heterogeneous resource endowments, economic and technological levels, and industrial structures across China's many regions, regional differentiation can significantly affect the design of pathways toward achieving carbon peak and carbon neutrality. Regionally coordinated low-carbon development may be the only way for the Chinese government to mitigate supply and demand imbalances in the distribution of energy resources and green technologies. China's interregional energy industry and pollution abatement collaboration have also created conditions for regional collaboration in low-carbon development. Nevertheless, successful regional coordination for low-carbon development requires overcoming the institutional problems.*

Keywords: *Carbon peak, carbon neutrality, regional coordination, industrial structure, energy mix, green technologies, low-carbon technologies*

JEL Classification Code: Q54, Q55, Q56, R11

DOI: 10.19602/j.chinaeconomist.2022.03.04

Carbon peak and carbon neutrality are major strategic objectives adopted by the Central Committee of the Communist Party of China (CPC), a stated commitments for taking part in global environmental and climate management (Liu, 2021). However, there is a great deal of regional heterogeneity in China's resource endowments, economic and technical conditions, industrial structure, and environmental capacity. While carbon peak and carbon neutrality programs are slated to be carried out across regions of various types in a state of unbalance, interregional coordination matters as well. In *Opinions on All-Round and Accurate Implementation of the New Development Concepts and Proper Implementation of Carbon Peak and Carbon Neutrality Work*, The CPC Central Committee and the State Council also called for "ensuring coordination and consistency for various regions and fields to achieve key targets, development directions, major policies, and major projects of carbon peak and carbon neutrality."

1. Regional Coordination in Low-Carbon Development

According to Climate Watch website (https://www.climatewatchdata.org), China faces a much shorter schedule for achieving carbon peak and carbon neutrality compared with developed countries. Additionally, China also faces unbalanced regional distribution of energy resources and low-carbon

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Acknowledgements: The General Project of the National Science Fund of China (NSFC) "Study on the Coordination and Optimization of Regional Low-Carbon Development Pathways for Achieving Carbon Peak and Carbon Intensity Targets" (Grant No. 71873143); the Key Strategic Project of the CASS Peak Strategy "Environmental Technical Economics" (Grant No. sjjzdxk2017).

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technologies, which calls for regionally coordinated low-carbon development. Regional coordination underpins the concept of creating a new paradigm for low-carbon development and implementing green and balanced development. The *Pre-2030 Carbon Peak Action Plan* issued by the State Council stresses that "various regions should advance local green and low-carbon development based on key regional strategies, promote coordinated regional development, create main functional zones, and pursue local green and low-carbon development in light of actual conditions." This requirement underscores the importance for various localities to consider local conditions and coordinate with other regions in formulating carbon peak action plans.

1.1 Supply and Demand Mismatch in the Regional Distribution of Energy Resources and Green Technologies

In China, there is a significant regional mismatch of supply and demand for energy resources. China's energy mix is dominated by coal, which is primarily distributed in western and northern regions, and oil and gas reserves are relatively small. Hydropower constitutes the bulk of China's renewable energy, but most hydropower resources are found in China's southwestern regions. In addition to coal and hydropower, China's western regions are home to 78% and 88.4% of the country's total available wind and photovoltaic energy resources, respectively (Wei, 2021). In contrast, China's major energy consumers are in the eastern coastal regions. Such a supply and demand mismatch has necessitated "massive and long-distance transportation of coal and oil from the north to the south and transmission of gas and electricity from western to eastern regions."[1]

Significant regional mismatch in the supply and demand remains for China's green technologies as well. A region's supply of green technology can be largely proxied by its amount and quality of green technology patents. According to the patent database of the China National Intellectual Property Administration (CNIPA), the level of green technologies has been increasing across China with a gradient decrease in green technological strength from the eastern to central and western regions; most green technologies are developed in more prosperous large cities, which are mostly located on the east coast (Sun and Zhang, 2022). China's western regions trail eastern regions in green energy technology application in high energy-consuming sectors such as nonferrous metals, electric power, steel smelting, and cement. Moreover, there has been no narrowing of the regional gaps in energy technologies, which means that the regional diffusion effect of energy technologies is insignificant (Wu, 2009). However, though technologically less advanced than their eastern counterparts, China's central and western regions still face the most urgent need to deploy high-tech solutions to decrease carbon emissions.

1.2 Regional Imbalances in Low-Carbon Development

After its reform and opening up policy was enacted in 1978, China prioritized the development of the eastern coastal regions with existing greater economic strengths in order to boost aggregate productivity. As a result, China's existing interregional development gaps widened. The eastern coastal regions have spearheaded nearly all technological advances, and in addition to strengths in human resources, economic fundamentals, public infrastructures, and geographic location, the eastern regions also benefited from national policy preferences for investment, taxation, foreign capital, trade, and finance. In the face of widening interregional economic and technological imbalances, in the late 1990s China adopted a strategy of beginning to develop its western regions, followed by similar programs to rejuvenate the northeast and promote the rise of the central region as well. Due to various constraints such as transportation and human resources, however, China's central, western, and northeastern regions still lag

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far behind the eastern regions in terms of GDP per capita reported by the National Bureau Statistics.

With more advanced technologies and industrial upgrades, the eastern coastal regions are also far more advanced than the interior regions in terms of low-carbon development. Although progress has been made in green and low-carbon technologies across all regions, the eastern regions of China are far more advanced than elsewhere. In recent years and especially after the 18th CPC National Congress, China's overall industrial structure has shifted towards low-carbon development, but the pace and effects of low-carbon transition are uneven across regions. While industrial restructuring in some provincial-level regions such as Beijing and Zhejiang is conducive to decarbonization, the carbon-reducing effects of industrial restructuring in other regions remain unclear (Zhang and Bai, 2021).

Given significant regional economic, technological, and industrial gaps, achieving carbon peak and carbon neutrality goals in a short period of time may be difficult, especially in regions that face barriers to economic development and lack industrial infrastructure for low-carbon development. This difficulty may be assuaged to some degree if more economically developed regions assist less-developed ones and low-carbon development leaders bring along the laggards to advance.

1.3 China's New Development Paradigm Can Benefit from Regional Coordination in Low-Carbon Development

China's current priority of creating a new development paradigm also seeks to integrate strategies for achieving high-quality development and carbon peak and carbon neutrality. In particular, carbon peak and carbon neutrality can be not only objectives of high-quality development but also part of a means to achieve the development as well, in line with the *14th Five-Year Plan and the 2035 Long-Range Goals*. In its new development paradigm, China is striving to create "domestic circulation" as the mainstay and domestic and international "dual circulation" reinforcing each other. As a key element of the new development paradigm, unimpeded economic circulation increases demand for coordinated regional development.

From the broader perspective of domestic circulation, regionally coordinated low-carbon development can indeed help integrate efforts to create a new development paradigm and achieve carbon peak and carbon neutrality goals. Such coordination also embodies the concept of green and balanced development. Under the framework of carbon peak and carbon neutrality, economic entities in various regions can cooperate with each other to help optimize the regionally differentiated layout of limited environmental and resource capacities, thus contributing to local economic development. While improving environmental quality, regional coordination for low-carbon development can encourage a wide range of green, healthy, and safe goods and services to be provided, such as organic food, innocuous detergents, energy-efficient and eco-friendly kitchen utensils, new-energy vehicles, and eco-tourism services, all contributing to increased domestic consumption in particular. In this sense, the promotion of regionally balanced low-carbon development can also be an important way to foster a new development paradigm.

From the perspective of domestic and international dual circulation reinforcing each other, regional coordination for low-carbon development can also be important way to support China's new development paradigm. With climate change receiving ever-greater attention from the international community, green and low-carbon development becomes key principles in international cooperation, according to the Paris Agreement. The new development paradigm calls for a higher degree of economic openness and better use of domestic and international markets and resources, and low-carbon development may play a key role in China's cooperation with the international community, may help to attract an inflow of more advanced foreign technology that can be used to support domestic circulation, and may improve trade.

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2. The Historical Origins and Current State of Regional Coordination in Low-Carbon Development

China's regional coordination in low-carbon development has a long history. As mentioned before, China's unique regional layout of energy supply and demand has given rise to close energy-industry links across regions, and regional coordination in low-carbon development can be framed as an upgrade or higher requirement of interregional energy-industry links. Moreover, China's regional integration initiatives for pollution abatement provide a precedent for regionally coordinated low-carbon development.

2.1 Close Interregional Energy-Industry Linkages and Long-term Development

China's regional economic ties were strong during the planned economy and have been so in the era since 1978. First, there have been close energy linkages between regions. Given the prominent supply and demand imbalances in regional energy resources, China has implemented major national energy strategies, including the transmission of natural gas and electric power from western to eastern regions and the transportation of coal from western and northern to eastern and southern regions. It invested heavily in the construction of infrastructure such as the Three Gorges Dam Project, gas transmission pipelines, the power grid, and coal transportation systems. Massive energy transmission from energy-rich regions satisfies energy demand in eastern coastal regions. At the beginning 2021, over 100 billion cubic meters of natural gas were transmitted annually from western to eastern regions. By the end of December, 2021, over 700 billion cubic meters of natural gas were transmitted from western to eastern regions, covering over 3,000 large and medium-sized enterprises and 500 million people in more than 400 cities in China's western regions, the Yangtze River Delta, the Pearl River Delta, and central region.[2]

Second, close industrial correlation already exists between regions. Various regions have already formed their pillar industries with strong interregional economic complementarity. For these reasons, China has strong interregional industrial correlations and large interregional trade volumes. According to the input-output tables of Beijing in 2017 (Economic Accounting Department of the National Bureau of Statistics, 2020), 45% of intermediate inputs in the municipality were goods or services transferred from other regions, accounting for 29% of its total output value, while intermediate inputs transferred out from the municipality to other regions only accounted for 17% of its total output value. Moreover, Beijing fully relies on external supplies of coal, petroleum, and natural gas.

Third, close interregional industrial ties have given rise to large interregional carbon emission transfers. Since all goods and services consume energy and generate carbon emissions, when one region purchases goods or services from elsewhere, it transfers the associated carbon emissions to other regions. Given China's large interregional trade volume, such interregional transfer of carbon emissions cannot be overlooked. According to Zhang (2018), there is a significant difference in the carbon emission responsibilities under the producer principle and the consumer principle for emissions responsibility allocation. Due to massive carbon emissions transferred via interregional trade (embodied emissions in trade), Zhejiang, Shanghai and Beijing's consumer responsibilities for carbon emissions are 60% to 190% higher than their producer responsibilities (Zhang, 2018).

2.2 The Effects of Regional Coordination for Pollution Abatement

In recent years, China has worked relentlessly to enhance and modernize environmental management with a view to improving environmental quality. Among various initiatives, interregional coordination for air pollution abatement in particular has achieved some success (Huang, 2022) and may

[2] Source: http://finance.people.com.cn/n1/2021/1228/c1004-32319228.html.

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serve as a reference for regionally coordinated low-carbon development.

First, the top-level design and top-down implementation of coordinated pollution abatement mechanisms across regions. In 2010, the State Council made decisions on air pollution abatement concerning key regions, major pollutants, and methods (for example, industrial restructuring, clean energy utilization, and the improvement of regional air quality monitoring) for pollution abatement, recognizing the importance of interregional coordination. Issued by the CPC Central Committee and the State Council on September 11, 2015, the *Master Plan for Institutional Reform for Ecological Civilization* called for establishing an interregional coordination mechanism for pollution abatement and improving coordination for air pollution abatement in key regions, including the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta regions, and the *Outline of the People's Republic of China 14th Five-Year Plan for National Economic, Social Development, and Long-Range Objectives for 2035* reaffirmed the importance of pollution abatement at the source, integrated pollution abatement methods, and coordinated control of multiple pollution sources and regional coordination to curb pollution.

Second, China has proactively explored initiatives for coordinated measures for air pollution abatement. For instance, the six provinces and municipalities in North China reached the first cross-jurisdictional agreement on environmental cooperation for a "Green Olympics" in 2008. Regional, interprovincial, and cross-departmental coordination was then carried out to curb air pollution and ensure much better air quality in Beijing during the Olympic Games. During the APEC meetings in 2014, Beijing took draconian measures to restrict cars and suspend coal-fired power plants and industrial activities so that "Beijing blue" might reappear. In a series of major events such as the September 3 military parade in Beijing in 2015 and the G20 Summit in Hangzhou in 2016, relevant regions and departments explored the scope and methods of regional coordination, targeted control, and concentration curtailment, which have all since become valuable experience for curbing air pollution.

As mentioned in *A Review of 20 Years' Air Pollution Control in Beijing* released by the United Nations Environment Program (UNEP) on March 9, 2019, Beijing has achieved daunting air quality goals in a matter of five years with PM 2.5 annual average concentration down 35.6% in 2017 from 2013 levels. From 2015 to 2020, China's heavily polluted days more than halved, and heavily polluted days in the Beijing-Tianjin-Hebei region and neighboring areas fell by about 6% (Yan et al., 2018). Thanks to the joint efforts of neighboring regions, the "Beijing blue" that appeared during the APEC meetings in 2013 has now become the "new normal."

3. Feasible Pathways for Regionally Coordinated Low-Carbon Development

Low-carbon development can benefit from sustained transition to low carbon emissions and green and low-carbon technology innovations. The low-carbon transition of economic structure entails the transition of industrial structure as well as energy production. Hence, the pathway for regionally coordinated low-carbon development can be considered in three aspects: Industrial structure, energy production, and technology innovations.

3.1 The Regionally Coordinated Low-Carbon Transition of Industrial Structure

Under the carbon constraint, the competitive strengths of various regions can be brought into play in order to optimize a combination of factors on a broader spatial dimension: The geographic layout of industries. In both theory and practice, pathways for regionally coordinated industrial structure optimization include industrial relocation and integration with diverse modes of coordination. Regionally coordinated low-carbon transition of industrial structure may follow the above methods and in doing so may be able to strike a balance between carbon emissions reduction and economic development.

First, a more efficient allocation of resources may be to relocate energy-intensive industries essential

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to national economic development to energy-rich regions. For instance, energy-intensive but less water-intensive industries may be relocated to energy-rich regions in the northwest (Pan et al., 2021) to avoid energy loss in long-distance transmission and allow energy-rich northwestern regions to thrive on their comparative advantages. With unique strengths in coal mining and dressing, China's southwestern province of Guizhou also is a desirable destination for industrial relocation for chemical processing, electric power generation, and heat production and supply as well (Zhang, 2020). In addition, methods of industrial relocation can be determined with flexibility, such as relocating entire enterprises, co-developing specialized industrial parks, creating the enclave economies, and relocating entire supply chains and related industries.

Second, regionally integrated industrial development may promote high-value industries for low-carbon industrial transition. One approach to such regional coordination is industrial agglomeration. In the Yangtze Economic Belt region with comparative advantages in advanced manufacturing, Shanghai may position itself as a global "sci-tech" innovation center while the neighboring provinces of Jiangsu and Zhejiang may develop supporting industries. In this manner, advanced manufacturing may cluster in the Yangtze River Delta, and industrial upgrade and low-carbon development can occur in the entire region. Moreover, with limited land available for development, the Yangtze River Delta region may relocate technology-intensive industries to the mid- and upper reaches of the Yangtze River in order to facilitate low-carbon transition.

Another approach to cross-regional industrial low-carbon transition is to develop high-end industrial chains with advanced technologies, high-value addition, and low-carbon emissions through interregional collaboration. For advanced manufacturing and other emerging industries, adjacent regions may rely on their comparative advantages and seek integrated development by fostering industrial chains through regional coordination to avoid redundant work and harsh competition. The Beijing-Tianjin-Hebei region, for instance, has made efforts to develop the hydrogen industry supply chain, where Beijing serves as the center for technological innovation, financial intermediation, and international exchange, and Tianjin and Hebei may specialize in developing and supplying special materials and equipment for hydrogen energy supply, storage, and transportation (Zhang and Bai, 2021).

3.2 Regional Coordination for Low-Carbon Transition

Regional coordination for low-carbon transition in China can be traced back far. Since the 2000s, the west-to-east natural gas transmission project has enabled the massive substitution of coal and other high-carbon-emission fuels with natural gas, re-optimizing the energy mix in regions along its route. By sending coal-fired power and hydropower to the eastern regions, the west-to-east electric power transmission project has reduced coal transportation costs and environmental pollution along the route while conserving thermal coal and re-optimizing the energy mix in the eastern regions as well.

However, the effects of those energy projects are merely regional, and further interregional coordination may be able to improve China's energy mix nationwide. The west-to-east gas and electric power transmission projects, though having effectively re-optimized the energy mix in the eastern region, did little to improve the energy mix in China's western regions and the energy mix nationwide. China's nationwide energy mix may benefit from further consideration being given to the improvement of the energy mix its western regions, and the development of new energy resources, most of which are located in China's western regions, to supplant coal-dominated energy production may indeed do just that. As the primary form of future interregional coordination for low-carbon transition, eastern regions can assist western regions with capital, technology, human resources, and training to tap into their huge reserves of new energy resources. By implementing the *Multi-Energy Complementary System Integration and Optimization Project* and the *Internet+ Smart Energy Project* according to local conditions, eastern regions may be able to increase the development of new energy resources such as

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wind, photovoltaic, and biomass energies and create distributed energy systems to ease pressures on coal-fired power generation and improve the energy mix in the western regions.

By slashing the share of coal in its energy mix, the western regions may only be able to meet local energy demand at the expense of disruptions to social and economic development in the eastern regions, which are heavily dependent on energy and especially coal-fired power generation from the western regions. Hence, the question of how indeed to re-optimize the energy mix of western regions warrants attention.

3.3 Regional Coordination for Green and Low-Carbon Technology Innovations

China is far behind internationally advanced levels in many areas of green and low-carbon technologies, especially zero-carbon and negative carbon technologies like new energy technologies, and depends on foreign supplies of critical equipment and components (Zhang, 2021). Regional coordination for innovations in green and low-carbon technologies may therefore benefit from focusing on weak areas and bottlenecks and from enhancing collaboration in order to make breakthroughs. In particular, green and low-carbon technology innovations can be spearheaded by businesses in partnership with universities and research institutions in future regional coordination. For instance, the development of a CO_2 cycle power generation test unit has followed a cross-regional approach involving over 30 participants,[3] including leading Chinese universities, research and design institutes, manufacturers, and construction companies. This regional coordination approach also applies to the research, development, and application of supercritical CO_2 cycle power generation in areas like efficient photo-thermal technology, electric thermal energy storage systems (ETESs), advanced nuclear power, and flexible thermal power.

Second, advanced technologies can be employed for monitoring and managing carbon emissions from cross-regional industrial chains in order to increase efficiency. Local governments may develop low-carbon and energy-efficient smart management systems that cover major energy consumers and monitor key sectors within their jurisdictions, establish a complete early-warning mechanism for industrial and supply chain problems, enhance problem analysis, proactively respond to emergencies, and promptly defuse potential risks. For instance, the Chengdu-Chongqing region in China's southwest has envisioned the application of big data technology to curb industrial carbon emissions. The region may consider joining hands with the neighboring Guizhou Province, which is known for its big data capability, to pioneer monitoring and controlling carbon emissions of industrial chains in pilot zones.[4]

Third, interregional coordination may lead to a community of green innovations that underpin regionally coordinated low-carbon development. Various regions may create a community of green innovations following the "center-periphery" model (Krugman ,1991) based on their respective strengths. As the pioneer of green innovations in the Yangtze River Delta region, Shanghai has been committed to developing into a sci-tech center with global influence. In December 2017, the Green Technology Bank (GTB), together with the GTB Administrative Center, was unveiled in Shanghai with a 3.5 billion yuan green technology commercialization fund, which created financial incentives for technology innovation and commercialization (Zhou and Hu, 2020).

Finally, the three primary pathways for regionally coordinated low-carbon development are highly consistent and not independent from each other, and two or three pathways can be followed at the same time. For instance, Beijing consumes coal-fired electric power from Inner Mongolia but also engages in new and renewable energy technology cooperation with Inner Mongolia (Yang, 2009). The two localities collaborate not only for green and low-carbon technology innovations but for energy transition as well.

[3] China's first CO_2 cycle power generation unit put into operation, http://www.cpnn.com.cn/news/kj/202112/t20211213_1465222.html.

[4] Chongqing Municipal Development and Reform Commission: "Joint Action Program for Carbon Peak and Carbon Neutrality in the Economic Circle of Chengdu and Chongqing (Consultation Draft)", http://fzggw.cq.gov.cn/hdjl/yjzq/202111/t20211119_9996222_wap.html.

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4. Strengthening Institutional Development for Regional Coordination in Low-Carbon Development

Pathways for regionally coordinated low-carbon development can be designed with respect to industrial restructuring, energy transition, and green and low-carbon technology innovations. However, we now turn to certain institutional and policy barriers, including barriers to the formation of institutional mechanisms and the lack of incentives due to inadequate institutional mechanisms or policies. Solving these problems can help facilitate the formation of regionally balanced low-carbon development pathways as well as keep those pathways stable in the long run.

4.1 Institutional Problems and Countermeasures for Regional Coordination for Industrial Restructuring

Interest distribution presents a key institutional barrier to regional coordination for industrial restructuring, and one decisive interest distribution mechanism is the fiscal system. China's tax sharing reform of 1994, also known as fiscal decentralization, has incentivized local economic development at the expense of interregional coordination for optimizing industrial structure and reducing carbon emissions. Such adverse effects have been amplified by the government's GDP-centric performance evaluation system and the division of administrative powers related to fiscal decentralization. Some eastern regions have been reluctant to relocate energy-intensive enterprises to western regions for fear of losing tax revenue（China Center for International Economic Exchanges, 2014）. The GDP-centric government performance evaluation system has also led some regions to be reluctant to relocate relevant enterprises over local GDP concerns.

Another concern is employment. Local governments in the eastern regions lack incentives to relocate energy-intensive enterprises, which not only contribute to tax revenue and GDP but employment as well（Jiang, 2009）. Moreover, investment projects across regions tend to become homogeneous. Under the above institutional mechanisms, localities may be tempted to engage in short-term projects with immediate effects. The dash towards repetitive projects, local protectionism, and vicious competition has prevented local governments from making efforts to improve industrial structure and has impeded national economic restructuring and low-carbon transition, especially if those repetitive projects were carbon-intensive. However, these problems may be alleviated by enhanced coordination especially with neighboring regions in industrial planning under carbon constraints.

However, some enterprises are reluctant to relocate to energy-rich western regions with unfavorable market systems, government services, support for industrial conditions, transportation infrastructure, and distances to markets. Moreover, the tax collection system based on the place of company registration rather than the place of taxable event has also discouraged some central and western regions from welcoming nonlocal enterprises, which make use of government services without contributing to local tax revenues.

The following six steps may address the above institutional problems. First, the central government of China can enhance the evaluation of local government low-carbon development performance to internalize low-carbon development as a major decision-making constraint. In addition, it can tighten the energy consumption and intensity, carbon peak, and carbon neutrality quotas for the eastern regions and moderately relax quotas for the western regions in an effort to smooth out usage among regions. Second, the government can view the creation of a new development paradigm as an opportunity to break through local administrative barriers, promote market integration, and allow the market to fulfill its role of optimizing resource allocation on a broader spatial scale by deepening market economic reforms and thereby increasing the efficiency of resource consumption and carbon emissions control both regionally and nationwide.

Third, various regions and especially neighboring regions can enhance industrial planning

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coordination under carbon constraints and seek alignment with major national strategies on regional development, including the integrated development of the Beijing-Tianjin-Hebei, the Yangtze River Economic Belt, the Guangdong-Hong Kong-Macao Greater Bay Area, the Yangtze River Delta, and the Yellow River Basin regions. Various regions can give focus on their own competitive strengths and facilitate regional industrial division of labor in an effort to enhance carbon reduction effects. Fourth, economic development zones or industrial parks in various regions can be encouraged to enhance industrial chain cooperation and division of labor, optimize cross-regional resource allocation, and improve cross-regional industrial chain competitiveness and carbon emission efficiency.

Fifth, proactive efforts can be made to develop cross-regional industry associations or similar cooperation institutions and platforms, to enhance dialogue between industrial chain enterprises, and to enhance dialogue between enterprises and local governments for industry-wide low-carbon development. Finally, energy-rich central and western regions can further improve their business climate and strengthen their infrastructure development to make more sufficient preparations for receiving energy-intensive industries with higher prospects for economic growth.

4.2 Institutional Difficulties and Countermeasures Facing Regional Coordination for Energy Transition

Institutional problems are the key barriers to both China's nationwide energy transition (Zhu, 2015), and its regional coordination for energy transition. The key to energy transition is new energy development, which faces impediments to market access and insufficient incentives, and the key institutional problem facing regional coordination for energy transition is the absence of a nationally unified electric power market.

The impediments in access to new energy market. Gaining access to power grid and administrative approval represent key challenges to new energy market access. Not only does it take a protracted review and approval process for new energies to access the power grid, but the construction of a secure power grid is costly as well (Qin, 2020). When power supply is abundant, some local governments in particular resort to administrative interventions to prioritize local coal-fired power generation and show little interest in absorbing new energy electricity from outside their jurisdictions（Li and Chen, 2018）. Administrative review and approval of new energy projects involve various departments in charge of land, forestry, electric power, and environmental protection with numerous administrative steps, overlapping review and approval rights, multiple administrative authorities, and repetitive administration (Zhu, 2015; Qin, 2020).

In addition, the incentives for new energy development are incomplete. New energy development in China is constrained by land, electricity tariffs, fiscal subsidies, and financial support limitations. With large chunks of land already occupied for economic development over the past few decades and ever-more stringent land space planning, China's land resources have become comparatively scarce, severely limiting new energy development. Regarding electricity tariffs, the problem has been that the cost of absorbing new energies cannot be effectively recognized in the electricity tariffs, thereby discouraging new energy absorption into the power grid, and the problem with fiscal subsidies is that it takes about two years for new energy enterprises to receive them. Regarding financial support, the new energy sector is a capital-intensive and high-risk sector faced with financing difficulties (Chen, 2011).

China's nationally unified power market has yet to be fully established, yet the electric power market is a key aspect of China's power system reform.[5] The first step toward fixing this may be to establish provincial electric power markets and cross-provincial regional power markets before improving cross-provincial and cross-regional electric power transaction mechanisms and establishing a nationally unified

[5] *Opinions on Further Deepening Power System Reforms* released by the CPC Central Committee and the State Council (Zhongfa [2015] No. 9).

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power market. Currently, some progress has been made in developing provincial and cross-provincial regional electric power markets, but a nationally unified power market has yet to be fully established, the absence of which prevents surplus electric power in some regions from being allocated on a nationwide basis and impedes regional coordination for energy transition.

Based on the above problems, we put forth the following policy recommendations. First, proactive efforts should be made to develop an electric power market for new energies (Shi, 2018), and legal assurance should be enhanced for new energy market access in order to reduce administrative intervention that is unfavorable to new energy development. The new energy project review and approval system should be gradually replaced with a ratification system. Second, preference should be given to new energy projects regarding land resources in order for terminal electricity tariffs to reflect fully the cost of absorbing new energies into the power grid (Guo, 2021). The distribution of fiscal subsidies to new energy projects should be improved, and green finance should be developed vigorously to meet the massive cash demand from new energy development. New energy consumption should not be included into the scope of control on total energy consumption and energy intensity. Electric power enterprises may be granted carbon emission credits for absorbing new energies. Third, the government should implement the *Guiding Opinions on Expediting the Development of a Nationally Unified Electric Power Market System,*[6] race to establish a nationally unified electric power market system with multiple regional hierarchies, consistent transaction rules and technical standards, and strengthen the groundwork for regional coordination for energy transition.

4.3 Institutional Dilemmas and Countermeasures for Regional Coordination for Green and Low-Carbon Innovations

Green and low-carbon innovations are characterized by "dual externalities," i.e. propelling technological progress and improving environmental quality. Aside from institutional dilemmas facing other technological innovations, regional coordination for green and low-carbon technology innovations also face unique institutional problems for which we propose the following solutions.

First, create reliable financing mechanisms. As a high-risk commercial activity, innovation often struggles to garner financial support other than venture capital, which tends to be insufficient on its own to finance innovation. The shortage of funds is particularly striking for green and low-carbon technology innovations, which are intended to address environmental problems but cannot generate lucrative economic return if environmental regulation is lax. In promoting regional coordination for green and low-carbon technology innovation, local governments should establish regionally coordinated green innovation funds, relax bond market restrictions, encourage venture investment, intellectual property rights (IPRs), subsidized insurance, and in particular vigorously develop green finance.

Second, facilitate the cross-regional flow of talent. Currently, many problems including those on professional authentication, social security, and public services still pose barriers to regional coordination for green and low-carbon technology innovation. In response, the government should create a cross-regional talent database, adopt a unified and scientific talent evaluation system, and recognize cross-regional technical and vocational qualifications to award green and low-carbon professionals with social security and public service benefits.

Third, the government should create a sound cross-regional, market-based interest and risk sharing mechanism for collaborative innovation in green and low-carbon technologies. In the absence of such mechanism, various regions have learned from each other but have had little cooperation and have worked separately. An important reason for this is that companies have yet to become the backbone of green and low-carbon innovation, and the government-funded mode of innovation is unlikely to

[6] Deliberated and adopted at the 22nd meeting of the Central Comprehensively Deepening Reforms Commission on November 24, 2021.

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form an interest and risk sharing mechanism on its own. In accordance with *Guiding Opinions on Creating a Market-Oriented Green Technology Innovation System* (Fa Gai Huan Zi (2019) No. 689), the government should enhance the status of enterprises as key players in green and low-carbon innovation and establish an interregional market-based interest and risk sharing mechanism that integrates industry, universities, research institutions, capital markets, and intermediary services.

Fourth, the government should expedite the development of a multi-tiered national green and low-carbon technology market. While the regional distribution of green and low-carbon technology innovations is uneven, the most innovative regions have a limited influence over other regions largely due to the absence of a national green and low-carbon technology transaction system to match the supply and demand of green and low-carbon innovations. Regional cooperation should be encouraged to establish cross-regional green and low-carbon technology transaction markets with standard operations, to foster intermediary service institutions and professional brokers, and to form a national green and low-carbon technology transaction market.

Finally, issues of legal assurance should be properly addressed. Despite overall improvements in China's intellectual property rights (IPRs) protection, some problems regarding green and low-carbon technology IPRs have yet to be addressed, including the sharing of profits from commercialization and the protection of relevant equity capital. Lax environmental law enforcement also discourages green and low-carbon innovations. Solving these problems requires improvements in relevant laws and regulations. In addition, regional coordination mechanisms should be established through work reporting, joint law enforcement, and regular meetings in order to enhance IPR protection.

5. Conclusion

Carbon peak and carbon neutrality have also become major constraints for China's development. As a basic principle for achieving its carbon peak and carbon neutrality goals, "national coordination" relies not only on differentiated policy-making according to actual conditions in various regions, but more importantly, coordinated policy-making between various regions as well. There is a prominent regional supply and demand mismatch in China's energy resources and green and low-carbon technologies. With intertwined interregional socio-economic relations and a policy vision for a new development paradigm, regional coordination for low-carbon development can become a feasible choice for China to make progress toward carbon peak and carbon neutrality. Judging by the key determinants on carbon emissions, we believe that regional coordination for low-carbon development should focus on industrial restructuring, energy transition, and green and low-carbon technology innovations and that related institutional mechanisms should be put into operation as soon as possible. This paper has made initial discussion on the pathways of regional coordination for low-carbon development, but further research is needed to address this policy issue at a deeper level.

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